

THE IMPACT OF FISCAL CHANGE
UPON RESEARCH ORGANIZATION
STAFFING STRATEGY

By

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PREFACE

Research managers have been devoting increasing attention to the need for applying sound management principles to their organizations. The cost of research, particularly when the use of monies must be rigorously and repeatedly justified, is no longer reconcilable to an often casual and unrefined approach to managing research groups. With the increased research cost, an increase in the time span between initiation of research and its fruition has occurred. This time span typically exceeds several budget cycles. The research manager, however, must assess his organization on a more frequent basis. This thesis covers one facet of the research manager's responsibility, that of assessing the potential results of staffing changes required in response to annual budget fluctuations. The environment from which data for this study were drawn is represented by two research laboratories in a National Aeronautics and Space Administration field center.

The research organization is treated as an input-output system, using personnel skills and labor costs as input and publications as output. The relationships developed between these parameters have permitted a staffing strategy to be developed for the particular organizations considered. The effects of changes in fiscal policy, as well as personnel policy, are evaluated in terms of effect upon projected output. In addition, a computerized program of evaluation has been developed which requires no special skills on the

part of the using manager. It is hoped that this program will be regarded as an added management tool available to the research manager.

I am indebted to Herbert Simon and Ben-Ami Lipetz, whose respective works suggested this area of study and the approach to be pursued. The Marshall Space Flight Center sponsored my academic program and provided background data. In particular, I am extremely indebted to Drs. William A. Johnson and Werner Sieber, Messrs. James A. Downey, III, Gerhard Heller, Clyde Hightower, and Ray Hembree for their support and encouragement.

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LIST OF SYMBOLS

α	- Tabulated or assumed confidence level of Student's t statistic
b_i	- The ith regression coefficient, $i = 1, 2, 3, \dots$
B	- Business/professional (NASA Class 600)
BGT_{FY}	- Labor budget for the current fiscal year
$BGT_{FY + i}$	- Labor budget for the ith ensuing fiscal year
C	- Clerical/secretarial (NASA Class 500)
D	- Difference between any two variables
IN	- Internal Note (may be followed by -A or -B to denote preparation by laboratory A or B, respectively)
ln	- The natural (Naperian) logarithm
M	- Number of independent variables in a regression expression
n	- Number of points in a data set
N	- Total number of personnel in a laboratory; the sum of T + S + B + S
NASA	- The National Aeronautics and Space Administration
NDF	- Number of degrees of freedom
No.	- Number
P	- Composite measure of report output; the sum of IN + TM
Pd	- A moving average time period, nominally a calendar quarter
QTR	- A calendar quarter (three months)

- $r_{1.234\dots}$ - The multiple correlation or regression coefficient between variable 1 and variables 2, 3, 4, ...
- S - Scientific/engineering professionals (NASA Class 200/700)
- s_{b_i} - Standard error of the i th regression coefficient
- SD - Standard deviation
- SE - Standard error of the estimate
- s_{X_i} - Standard deviation of the variable X_i
- $s_{y'}$ - Estimated standard deviation of the predicted variable y'
- S/C - The ratio of scientist/engineering personnel to clerical/secretarial employees (may be followed by -A or -B to denote the ratio for laboratory A or B, respectively)
- t - Student's t statistic (t will be capitalized on computer printouts)
- T - Technicians (NASA Class 300)
- TM - Technical Memorandum (may be followed by -A or -B to denote preparation by laboratory A or B, respectively)
- TN - Technical Note
- TR - Technical Report
- X_i - This or any other character not listed herein stands for the i th variable of a data set
- \bar{X} - Mean value of the data set of a variable X
- y' - Dependent variable predicted from a regression equation
- \$ - Best option for effective cost/report

Σ - Summation of a variable whose range is from one to n

* - Best option for report output

CHAPTER I

FORMULATION OF THE PROBLEM

Background

The research manager in a contemporary technological organization is in an unenviable position. He is nominally the superior in a group which approaches the conditions for "the free circulation of the elite" as described by Barnard (2). His subordinates desire more of everything: funds, research assistants, facilities, time. His superiors want results, often according to a near-impossible schedule. His colleagues in production or development have visible objects against which progress can be measured. While research generates new knowledge, products or projects, it also becomes increasingly more expensive over time. In times of prosperity, this is not a severe handicap, but in times of recession, it can be crippling. In addition to these difficulties, relatively little "research on research" is directed toward alleviating the problems faced by the research manager. Such research on research has been directed primarily toward determining what factors influence creativity. Investigations having any connotation of applying scientific management to research personnel have been resisted by the researchers. Their principal theme is that the establishment and maintenance of management discipline is a sufficient condition to reduce or even

destroy creativity. This has been particularly well stated by Stuhlinger (18), who paradoxically presented an eloquent case for the professional research manager.

However, the resistance to ordinary management controls over research has decreased in recent years. Although researchers still believe, as described by Pelz and Andrews (13), that individual freedom, special incentives, and special privileges are desirable for promoting creativity, the increasing cost of research and competition for research funds have exposed the need for researchers to exercise sound judgement (good management) over their activities. One of the problems facing the research manager in his exercise of direction over his staff has been the lack of a suitable measure of the performance for his organization.

Because research is, a priori, inefficient and often ineffective, any measure which may be contemplated must be used with caution and due regard for its limitations. Anything which may threaten the creativity of the researcher is cause for concern by both the research manager and his research staff. Remembering this, Lipetz (8) proposed the use of reports as a potential measure of output:

Except for the fallacy of assuming equal usefulness for all publications, measurements of effectiveness based upon measurements of the number of publications produced are highly scientific research organizations. The production of publications is . . . research achievement, and is a common practice to most research organizations. In many research organizations, publications constitute the only tangible achievements. The counting of publications is a simple, undemanding process which is objective, yielding cardinal numbers linked to standard units

. . . . The making of such measurements should not, in most research organizations, be appreciably costly or disruptive.

Karger and Murdick (7) also advocated publication output, as well as ratios of staffing and salary levels, for use in determining the state of health of the research organization. They, as did Lipetz, recognized that there were limitations to these measures, since they could not entirely replace the qualitative and usually subjective judgement of the research manager. However, they believe that such criteria, used properly, could be of considerable assistance to the research manager. One immediate and desirable benefit from the use of such criteria is a mechanism for determining the staffing of a research organization under various conditions. In the two organizations which will be examined more closely in the following discussion, the policy which has been more or less followed has been one of proportional increases or decreases. The increase or decrease has depended upon the availability of personnel funding. In view of Wyskida's investigation (19) into staffing of aerospace contractor work forces (primarily for development), the question has naturally arisen as to whether the idea of skill-mix ratios might also be applicable to research activities alone.

This presupposes that the research organization can be treated as an input-output system, as illustrated in Figure 1. Obviously, there are real inputs to the organization, in the form of personnel, funds, facilities. Just as obviously, there are outputs in the form of research achievements. While these outputs may be of low visibility and perhaps of dubious utility, they

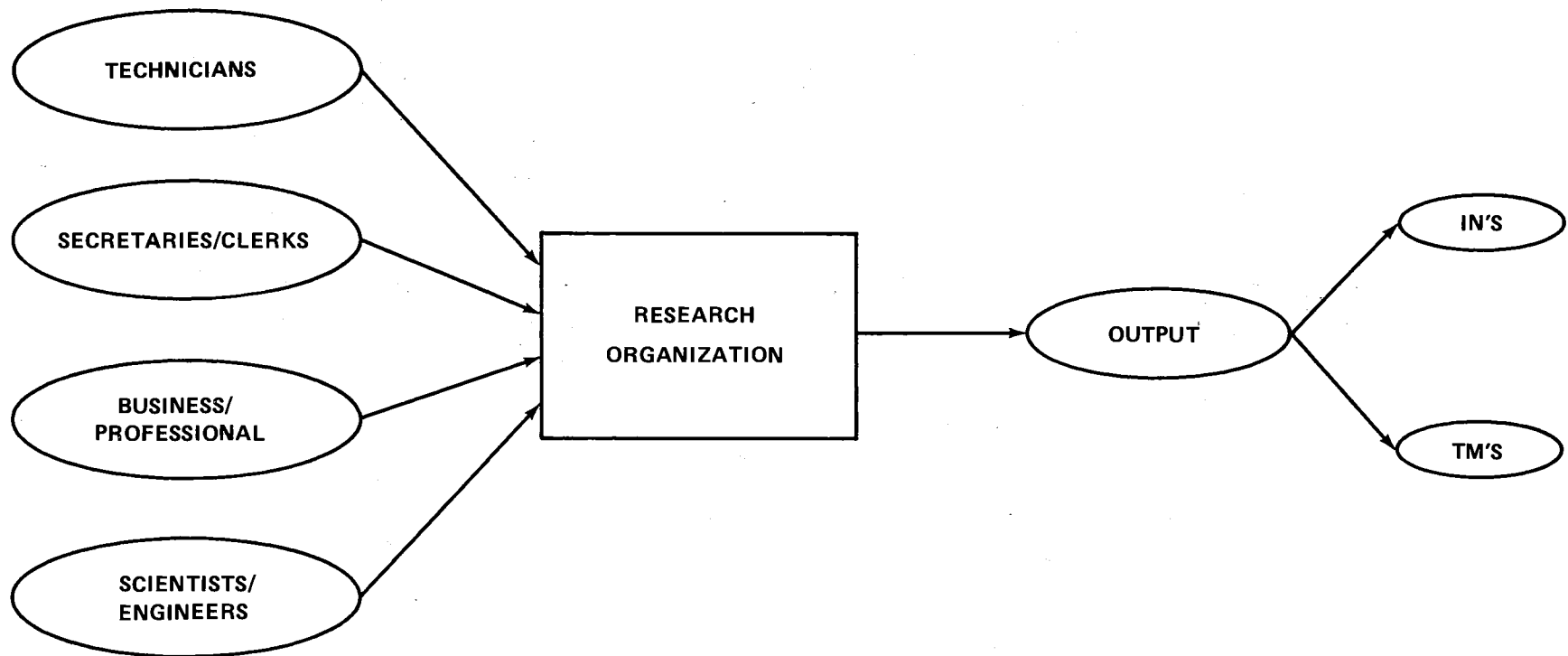


Figure 1. Simplified Illustration of the Research Organization as an Input-Output System.

are required of the research group. Just as in the industrial sector, a poor profit center does not exist long; therefore, in the milieu of research must the research organization show results of some satisfaction to its superior organization or forfeit its claim for existence. It is then necessary to demonstrate that an apparent relation exists between some input variables and at least one output variable. This is the first major objective of this study.

The second major objective is to apply such a relationship. As noted by Lipetz in the above citation, the use of reports as an output indicator is attractive. Further, in the two organizations studied for this effort, reports are the only countable output. The number of papers are cited by the two laboratory directors at their annual review to their superiors. It should be noted that "the fallacy of equal usefulness" mentioned by Lipetz does not appear to be a serious detriment. Usefulness or utility is determined by the user rather than the producer, although the latter quite frequently indicates how his product may be of benefit. For the purpose of this study, it will be assumed that the continued existence of the organizations is prima facie evidence of the desirability of their efforts on the part of the larger organization to which they belong.

However, the foregoing policy of staffing is a matter of interest. Even granting that an apparent relationship may exist between input and output for the research organization, it does not necessarily follow that the policy which has been followed in the past is altogether satisfactory. The application of this so far postulated relationship is directed toward determining how the research organization should or may be staffed.

Staffing Strategies

Besides the rather loose strategy already mentioned, there are other alternatives available to the research manager. There are basically four conditions under which the research manager must plan his research organization's staffing. The first is a growth situation; i.e., the projections for the ensuing few years indicate that the organization will continue to increase in size (and annual budget). While it is customary for the organization to conduct its own periodic review of the utilization of resources, the government organization is also subject to occasional audit by the General Accounting Office, the Civil Service Commission, and by the Congressional committee or subcommittee under whose jurisdiction the organization receives funding. Thus, the research manager, lacking though he may be in analytic/quantitative methods of evaluation for his organization, must provide a satisfactory accounting for his stewardship. Even though growth quite frequently is accompanied by a sense of urgency which tends to obscure the need for thrift, the government research manager is always aware of a later requirement to defend his past actions.

The second condition, which occurs coincidentally with periods of economic recession, is that of decline. Here, the pressure is not from any need to account for past actions but is from the necessity to use funds and resources economically so that the required research services can be continued. Thus, the previous addition of high-salaried researchers during periods of growth no longer appears so attractive under this situation. Even

though such personnel form the core of the research organization, it is nonetheless true that maintaining one researcher may well result in the loss of two or more needed technicians. Is this always a necessary consequence of research staffing? The research manager is asked this question by his management. The answer is not always well supported by fact.

The third and more usual condition is a mixture of growth and decline, depending almost entirely upon factors external to the research organization. However, the research manager must adjust to it in the best way he can, and subject to the concerns relating to growth and decline which were just described. The last major condition is denoted "retrospect." In this instance, the two laboratories of interest have existed for some time. It is sometimes instructive to review past history to see what might have been the results had a different course of action been followed. Of course, it is not possible to recreate the past, so retrospective review must be treated cautiously. Even so, it is believed worthwhile to consider this situation.

It is possible that there is a fifth situation, which is neither growth nor decline. This would be a stable condition. Although its existence is recognized, it is not treated in this study. The primary reason is that both research organizations used in the study are staffed under Civil Service Commission regulations. Thus, the government research manager does not have the freedom to adjust his personnel levels as does his counterpart in industry. He can make small adjustments, if deemed necessary, as a consequence of attrition through resignations, retirements and deaths. A major adjustment, however, can only be made during periods of growth or decline.

Four options are available to the research manager operating under Civil Service Commission regulations. The first option applies to either a growth or decline condition. It is a strategy of increasing or decreasing all personnel categories by the same proportion; i. e., if the anticipated labor budget is increased by 10 percent, for example, then each category may be increased by 10 percent. As defined here, it is assumed that the increase or decrease occurs at the beginning of the ensuing fiscal year. This approach is normally followed in actual practice, particularly when it is necessary to reduce the work force. A special case of this option is where one skill classification is increased or decreased in proportion to budget changes while holding all other classifications at their current level. This does not appear to have ever been rigorously followed, as later examination of the staffing data will show. While it may have application on an individual basis, the more usual form of the first option, as presented, seems to have been followed.

The second option also assumes that the increase or decrease occurs at the beginning of the ensuing fiscal year. However, it is postulated that there are certain ratios of personnel classifications which are desired to be maintained or improved. Accordingly, this option is somewhat more complex than the preceding option. The third option pertains only to a projected decrease in labor funding. This option consists of reducing the work force in quarterly increments, with no attempt to maintain any desirable classification ratios. It is basically the first option, under a condition of decline, which allows the effects of attrition to be included in a quasidynamic fashion.

The fourth option is the preceding option, which is modified to maintain or improve desirable classification ratios.

It is possible that the research manager, given the opportunity to evaluate various staffing alternatives, may choose to use one strategy during a growth period and another during decline. It is also possible that he may be directed to reduce according to a predetermined strategy. By evaluating the possible consequences, in terms of input-output, he may be able to influence the decision to follow a predetermined plan. Failing this, he may proceed to evaluate available options with a view toward overcoming any adverse consequences from such decisions.

Related Theory

Although, as mentioned earlier, there has been reluctance by scientific personnel to accept the imposition of scientific management principles over their activities, a growing body of knowledge exists that suggests that such an imposition not only can be done but may even be advantageous to the researchers. Recent articles in various scientific journals have indicated that the research scientist has an obligation to use his resources well. The current debates over ecology bear this out. However, this does not mean that the researcher is to be regimented in the same manner as an assembly line worker. Rather, it means that the research manager must use management practices which have been used in more production-oriented organizations. The elegant and descriptive theory of organization described by Barnard (2) applies to the research organization. In fact, Figure 1 is

suggested by Barnard in his discussion of cooperation and of effectiveness and efficiency. Pelz and Andrews (13) and others have delved into the research environment to understand how it operates. However, this forms a general theoretical background. The works of Simon (16, 17) and Shockley (15) are of more immediate concern.

Simon considered a class of skew-fit functions, which included publication output of selected populations. Although his populations were not well-defined nor well-bounded, he was able to derive an empirical relationship between numbers of authors and numbers of publications. This in itself is indicative of an input-output relationship, although the support required by the authors was not considered. Further, Simon considered the process as stochastic, thus laying the foundation for statistical treatment. Shockley, who essentially followed the work of still another investigator, presented findings between researchers and the number of papers produced. While he was more concerned with presenting a case for premium pay for researchers, he nonetheless established that the distribution tended to be logarithmic. This is not remarkably different from the skew-fit functions of Simon. It suggests that the mechanism may be multiplicative, rather than additive, as a consequence of being logarithmic.

The research organization can also be considered to be a service organization, rather than a production organization. This in no way detracts from it being an input-output system. Penrose, as reported by March (10), investigated such organizations by treating their personnel as directly concerned with administration or with operations. While other

examples could be cited, the foregoing indicates that this study is a logical extension of previous investigations.

Research Problem

The basis problem, composed of two major parts described previously, is (1) to determine if there is an apparent relationship between input and output for a research organization and (2) to apply this relationship in a manner which will allow a research manager to assess various situations that he may face. It is restricted to personnel (input) and reports (output). There are three major reasons for this. First, Harrold (5) has shown that there is a very weak relationship between performance and funding of a research organization. (He obtained a beta coefficient of 0.003, using publications, inventions, and patents as output criteria). Second, it is desirable to keep the investigation as well-bounded as possible, without being trivial. The use of reports as an output measure, while desirable from a management view, is not well accepted nor is the need to do so well recognized by researchers. Hence, an uncomplicated problem formulation is considered necessary. The third reason is due to the problem environment itself. The one variable, or class of variables, over which the research manager has jurisdiction is personnel. The other variables — facilities, equipment and project funds — are essentially fixed or of the nature of being provided if research is to continue. This does not mean that there are not alternatives available in determining how to provide facilities and equipment. Rather, it means that the research manager is

committed to a particular approach once research resources are allocated to his organization. He can influence his researchers in the direction of new research, but he had little leeway with research projects already approved.

The approach taken to the research problem was as follows. First, NASA skill classifications for each of two research laboratories in a NASA field center were used as the input variables. Reports of the two organizations were used as an output measure. Because more than one type of report is produced by each of the laboratories, a composite variable has been defined in terms of the two major types of report. This is because a single variable is better handled in the subsequent regression analysis. While both organizations are staffed according to NASA and Civil Service Commission regulations, and hence are similar in terms of organization, skill categories, and grade levels, it was necessary to determine if the staffing ratios are similar. This is considered a dynamic indicator of similarity between the two organizations.

A portion of the data from one laboratory was used to obtain a regression function relating input and output. This function was then used to predict the remaining output variables, using the remaining input variables for that laboratory. The differences between observed and predicted output variables were tested. Next, the obtained regression function was used to predict output of the second laboratory. Again, a test was made on the difference between observed and predicted output variables. Because the data used was time based, it was also necessary to test for autocorrelation.

This is because the existence of autocorrelation tends to reduce the information which can be obtained from a given set of data.

The approach was followed in attaining the first objective. For the second objective, confidence limits were established for the individual predicted variable. Then, a computer program was written which is capable of considering the staffing plans or strategies most likely to be considered by the government research manager. These presumed an anticipated initial salary level and rate of inflation/salary increase for the following strategies:

- a. Increase/decrease all skill classifications equally.
- b. Increase/decrease all skill classifications to maintain or improve predetermined staffing ratios.
- c. Decrease all skill categories sequentially over time and by equal increments.
- d. Decrease all skill categories sequentially over time and to maintain or improve predetermined staffing ratios.

The results of these strategies, using predicted output and unit cost per unit output, are compared and the appropriate strategy recommended for the conditions of (1) growth, (2) decline, (3) mixed growth and decline, and (4) retrospect.

CHAPTER II

DATA

Environment

The organization from which data for this study were taken is one of the National Aeronautics and Space Administration's (NASA) field centers. A simplified, current block diagram of the Center is shown in Figure 2. The portion identified as the Science and Engineering (S and E) Directorate has existed virtually intact since the establishment of the Center in fiscal year 1960 (except for changes in titles or organizational names). Figure 3 depicts a further breakdown of the S and E Directorate. As indicated, there are seven discipline-oriented laboratories. While each of these laboratories are involved in both research and development of NASA's space hardware, the two identified as A and B in Figure 3 have been predominately involved in research, as opposed to development. Consequently, these two organizations were selected as being most appropriate to the study described herein.

The organizational structure of these two laboratories is identical and is shown in Figure 4. Although the divisions shown in Figure 4 are further subdivided into branches, these subdivisions are primarily administrative

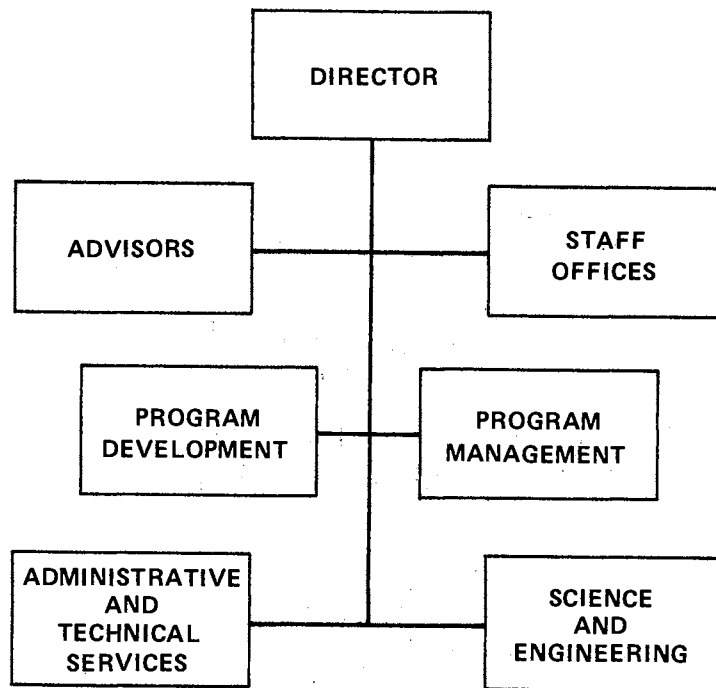


Figure 2. Field Center Organization Chart.

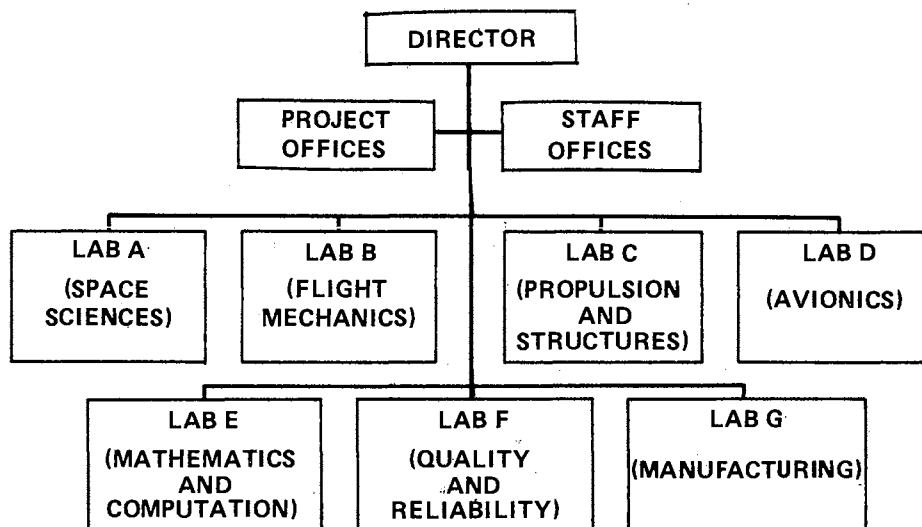


Figure 3. Science and Engineering Directorate Organization Chart.

in nature, rather than functional. The missions of the two laboratories, as indicated by the following citations from the Center's Organizational Manual (11) are virtually identical in nature, although the respective areas of interest are different:

Lab A: To initiate and execute . . . research in selected scientific and technological fields

Lab B: To conduct research . . . to advance related sciences.

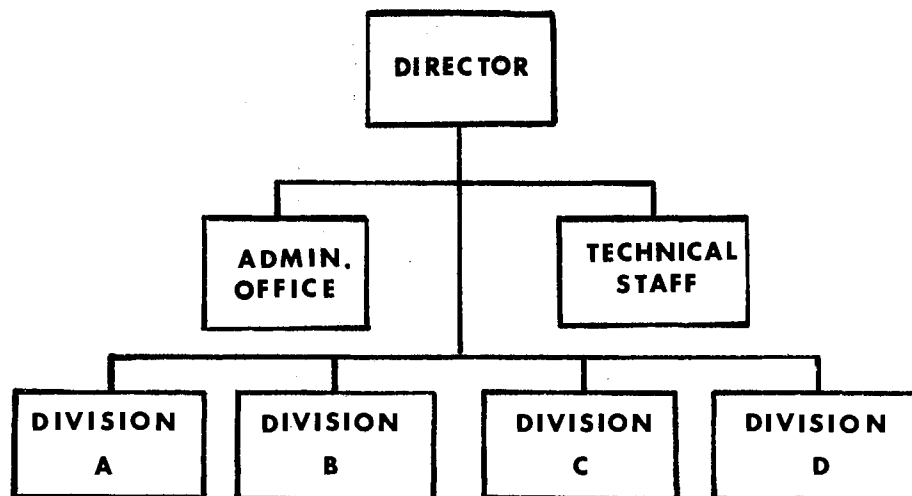


Figure 4. Organization Chart for Laboratories A and B.

Lab B has historically been the larger of the two laboratories. Both organizations are staffed according to Civil Service Commission regulations as further defined by NASA personnel policy. Of particular concern is the following breakdown of skills under this policy (14):

- a. T (Class 300) — Technical support (technicians and sub-professionals).
- b. C (Class 500) — Secretaries, file clerks, and typists.
- c. B (Class 600) — Business/professional (accountants, program analysts, personnel specialists, and other nontechnical professionals).
- d. S (Class 200/700) — Scientific and engineering professionals.

Because of the overall Civil Service staffing requirements, the grade structure, education, experience, and other demographic quantities are homogenous relative to both organizations. Both laboratories have no countable output other than reports.

There are four classes of official technical reports authorized by the Center, as defined by one of the Center's Management Instructions (9), they are:

IN - Internal Note: These publications present timely information for use by personnel directly concerned with the information reported and having a need to know

TM - Technical Memorandum: These publications present information which is given limited distribution

TN - Technical Note: These publications present information lacking some characteristics They contain preliminary or interim information which indicated a trend, show an approach, or propose a method of solution

TR - Technical Report: These publications present information considered to be complete, important and of lasting interest

In actuality, report output of the selected laboratories has consisted almost entirely of IN's and TM's. Therefore, for ease of analysis, the few TN's and TR's were counted as TM's. Since these number less than 20 out

of a total of approximately 1000 reports, it is felt that no adverse effects have been introduced by this treatment.

Constraints

Investigations into organizations and management practices are restricted by an economic fact of life which normally does not confront the scientist; i. e., the scientist can formulate a theory, build a model - physical, symbolic, or mathematical - and obtain experimental data. Further, the scientist can duplicate his experiment under controlled conditions. This is because of the economic impact upon the organization(s) of concern; union restrictions, stock-holders' objections, and other reasons. Thus, the investigator must be satisfied with data obtained in situ from records normally maintained by the organization(s) of interest or from questionnaires and similar types of sources. If the investigator is fortunate, he may be able to demonstrate that new records which he may require for data will also be of value to the organization(s) under study. In either case, the investigator is constrained to an uncontrolled experiment.

Notwithstanding this limitation, data from an uncontrolled situation may be analyzed to determine functional relationships and to postulate theoretical statements. The nature of such analysis normally requires the use of mathematical/statistical techniques. This study uses a symbolic model, developed from the application of statistical methods, to represent the two laboratories of interest. Since the investigator could not manipulate either

organization to verify the findings of the study, it was necessary to depend upon statistical validation of the model. Two approaches were taken. In the first case, part of the data was withheld. By using the developed model to predict output from the withheld data, the observed output was compared to the predicted output to ascertain how good the model represents the situation being modeled. In the second case, the regression function obtained from one set of data was used to predict output variables from the input variables of the second set of data. Again, a comparison was made between predicted and observed values.

This approach has presumed that the system(s) being modeled is stable over time; i. e., it is assumed that the fundamental process or processes which characterize the conversion of input to output did not fluctuate greatly over time. Such a supposition is easily accepted since frequent or extreme fluctuations suggest instability in the organization being represented. Unstable organizations seldom exist long; hence, the relative age of the two organizations being studied is a posteriori evidence of stability.

Assumptions

Development of a statistical model is predicated upon one or more general assumptions. Such assumptions are necessary either (1) to justify the use of the statistical techniques required to develop the model or (2) to bound the system being modeled to a reasonable state of conditions. The major assumptions required for this study are as follows:

1. Time is a passive medium, serving only as a vehicle connecting data points of each set of variables. The goodness of this assumption may be checked during the data analysis portion of the study by testing for autocorrelation.

2. The data obtained have been accurately reported; i.e., reporting errors do not exist. Since government organizations historically have had a penchant for reporting data for time and payroll purposes (incorrect reporting is universally regarded as a breach of discipline), such an assumption appears to be reasonable.

3. Personnel actually work according to duties described by their respective position categories; i.e., secretaries do not work as laboratory technicians nor scientists as program analysts.

4. Reports are released on the date of issue indicated by the report cover page. Since primacy of publication is a tenet of scientific groups everywhere, it is reasonable to presume that the author(s) and their organization encourage prompt release of reports.

5. Report output is independently distributed. This is an explicit restatement of the first assumption for the report data. This assumption, which may be checked later, and the following assumption are required so that regression analyses be legitimately used.

6. For a given set of input (independent) variables, the associated output (dependent) variable is approximately normally distributed. Since parameters of sample sizes of over 20 tend to approach a normal distribution, this is not an unreasonable assumption. However, because there is only one

data point for each set of input variables, it is not possible to test for normality. Since the use of regression theory does not require strict adherence to normality, and since there is no reason to suspect nonnormality, it is believed that this is a safe assumption.

It should be noted that as discussed by Ostle (12), the assumption of causality is not required for the use of regression techniques. One purpose of this study is to ascertain to what extent output of a research organization may be determined by the defined input variables. Hence, it is believed that the assumption of causality is not required in this study and may even be misleading. For example, if such an assumption were made, there would be a temptation to accept the developed regression model for other research organizations. Since this obviously cannot be demonstrated, it is better omitted. Indeed, Ezekiel and Fox (4) specifically state that the regression model imposes no requirement that the distribution of variables be representative of any universe at all. Further, any conclusions which may be drawn from whatever relationships that may be developed will apply only to a situation which is identical to that which initially provided the data for the developed relationship.

Sources

Several sources provided the data required for this investigation. The Center's Personnel Office provided most of the data pertaining to personnel categories; however, these data were augmented by records from the Center's Historical section (1) and from working papers maintained by various staff

offices (6) having cognizance over such matters. Budget data and salary information were provided by the Financial Management Office and also by appropriate staff offices. Publication data were taken from material maintained by the Center's technical library and technical writing personnel.

The study data come from a 10-year period and is provided in quarterly increments over this period of time. The selection of quarterly increments was based upon two considerations: (1) the need to provide a sufficient number of data points to perform a meaningful analysis and (2) the need to avoid the introduction of error by using end-of-year and end-of-semiannual strength levels.

Besides disseminating technical data, both laboratories have used IN's and TM's for certain routine administrative releases; i.e., summaries of organizational activities, active projects, and laboratory progress reports. These reports were prepared by either staff or administrative personnel and are excluded from the report totals shown in the tables of data listed elsewhere.

Hypotheses

Because the approach to this research problem relies upon statistical analysis, it is appropriate to list the specific hypotheses that were tested. The major hypothesis, of course, was that output (reports) is related to input (personnel skill classifications). This required two subsidiary hypotheses. First, to demonstrate dynamic similarity of the two research laboratories, the null hypothesis was that no difference existed between the

various staffing ratios of the two organizations. Second, to obtain a single composite output variable, it was hypothesized that the two major types of reports are equally good; i.e., it is possible to simply sum the two types of reports and use this sum as the output indicator. However, there may be a built-in bias in favor of one particular type of report. To test this hypothesis, it was necessary to conduct a survey of the two organizations. Since it is not possible to go back in time, it is necessary to assume then that the results obtained hold true over the entire 10-year period covered by this study.

The use of the regression function as a predictive device requires testing of the hypothesis that no significant difference exists between observed and predicted output variables. (Further, these data must not have been used in obtaining the regression equation.) Also, a similar hypothesis is that the regression equation obtained from data of one laboratory is equally good for predicting the output of the other laboratory.

Because the data are time based and even though it was assumed that time is a passive medium, it is considered necessary to test the differences between observed and predicted values of autocorrelation. The null hypothesis is that no significant autocorrelation exists.

Since the obtained regression equation is to be used in predicting output under various staffing options, it is hypothesized that these options are not equally good under conditions of (1) growth, (2) decline, (3) mixed, and (4) retrospect. The approach taken to determine which staffing option

is appropriate for the several conditions relies upon graphical analysis; i. e. , the program used for projecting output under the various situations of interest provided data in the form of tabulations and graphs. Review of these sets of data permitted the selection of results according to the various situations.

CHAPTER III

INPUT-OUTPUT ANALYSIS

Lag Effects and Moving Averages

The basic data used for this study is presented in Tables I, II, and III. During the preliminary stages of the study, extensive use of scatter diagrams indicated various trends of relations between input and output. Because research is performed over time, it was anticipated that there would be lag effects obtained between the output and input variables. Further, it appeared that in some instances there was an equally strong relation between input and output for more than a single lag value. This suggested that the use of moving averages might be beneficial in arriving at an expression relating input and output. The use of moving averages was also attractive since a smoothing effect on the data would be obtained.

The objections to using moving averages appeared to be minor. First, the raw data would not be used in any formal regression analysis since a series of moving averages is in effect a transformation. However, the use of transformations, according to Ezekiel and Fox (4) and to Ostle (12) is common in performing regression analyses. Second, the use of moving averages complicates the analysis and interpretation of results. Nonetheless,

TABLE I
LABORATORY A PERSONNEL STRENGTHS BY
QUARTERS OVER A 10-YEAR PERIOD

QTR	T	C	B	S	TOTAL
1	5	6	2	34	47
2	5	8	2	35	50
3	6	6	2	38	52
4	8	7	3	39	57
5	7	7	3	43	60
6	9	6	3	42	60
7	10	8	3	45	66
8	7	7	4	45	63
9	7	8	4	51	70
10	8	7	4	51	70
11	10	9	4	58	81
12	10	9	5	60	84
13	12	12	4	72	100
14	11	13	5	70	99
15	11	15	6	72	104
16	15	12	6	69	102
17	10	12	7	67	96
18	9	11	5	66	91
19	12	12	6	63	93
20	10	10	6	61	87
21	11	12	7	66	98
22	11	14	7	70	102
23	11	12	9	71	103
24	11	14	8	78	111
25	13	13	8	86	120
26	14	11	5	71	101
27	13	15	4	80	112
28	17	14	7	92	130
29	16	14	7	92	129
30	18	16	7	92	133
31	15	15	6	88	124
32	15	14	6	86	121
33	17	12	5	82	116
34	14	17	7	96	134
35	15	18	7	96	136
36	23	15	7	98	143
37	15	15	9	97	136
38	14	14	9	90	127
39	19	14	9	96	138
40	22	16	7	95	140

TABLE II
 LABORATORY B PERSONNEL STRENGTHS BY
 QUARTERS OVER A 10-YEAR PERIOD

QTR	T	C	B	S	TOTAL
1	19	24	2	127	172
2	25	24	2	138	189
3	29	26	2	157	214
4	23	28	2	148	201
5	30	31	2	153	216
6	27	30	2	169	228
7	36	32	2	187	257
8	31	33	3	172	239
9	40	41	3	228	312
10	41	42	4	234	321
11	42	49	4	238	333
12	39	48	4	262	353
13	38	46	4	273	361
14	38	45	5	263	351
15	39	44	5	258	346
16	49	48	6	265	368
17	38	50	6	269	363
18	47	46	6	275	374
19	49	41	6	276	372
20	41	41	6	269	357
21	48	41	6	258	353
22	43	42	6	259	350
23	44	43	5	257	349
24	43	43	5	258	349
25	46	46	5	276	373
26	42	42	5	249	338
27	51	41	5	268	365
28	49	43	6	271	369
29	44	43	6	263	356
30	40	38	6	251	335
31	40	36	6	252	334
32	37	38	6	254	335
33	38	41	6	255	340
34	36	36	6	253	331
35	35	35	6	251	327
36	38	35	7	249	329
37	40	34	7	228	309
38	39	33	8	228	308
39	38	32	8	223	301
40	37	31	8	219	295

TABLE III
 REPORT OUTPUT FOR LABORATORIES A AND B
 OVER A 10-YEAR PERIOD

QTR	IN-A	TM-A	IN-B	TM-B
1	8	5	5	28
2	3	6	0	18
3	4	9	11	18
4	3	8	8	8
5	4	6	7	25
6	6	9	6	19
7	4	10	10	34
8	2	6	8	7
9	3	4	11	25
10	7	14	9	16
11	10	8	12	18
12	4	8	9	0
13	5	8	13	14
14	5	12	8	19
15	10	7	14	20
16	9	3	6	4
17	0	8	7	19
18	6	16	6	16
19	6	10	6	24
20	6	4	3	15
21	2	14	8	21
22	3	12	8	18
23	8	7	6	11
24	7	5	5	24
25	2	16	8	22
26	3	8	8	17
27	13	15	2	14
28	6	4	0	29
29	2	12	6	16
30	5	11	10	11
31	13	16	2	10
32	4	6	4	27
33	4	7	5	9
34	2	16	4	11
35	13	15	5	15
36	8	0	4	23
37	0	9	4	16
38	6	12	3	12
39	1	18	5	8
40	6	10	2	10

they are used frequently to remove periodic fluctuations in data series. The use of regression theory is in no way affected by the use of moving averages, since each data point used in regression is a sample of how many points are used in the moving average. The crucial assumptions of independence and randomness required of the dependent variable, as stipulated by Ostle (12) are not invalidated by the use of moving averages. The major problems in using them, as well as lags between the several series of data, were the loss of degrees of freedom (important for various statistical tests) and selection of which moving average to use.

Obviously, the moving average used must be the same for all data series. Just as obviously, lags used for respective series for the two laboratories had to be the same, although different lags between data series of the same laboratory would be acceptable. The scatter diagrams suggested that a moving average taken over four calendar quarters was the most satisfactory for both laboratories. This is taken as a further indication of similarity in behavior of both organizations as input-output systems. Likewise, the respective series of data for the two laboratories yielded similar lags between dependent and independent variables.

Staffing Ratios

Another indication of similarity of the two organizations was hypothesized as being no significant difference between the like ratios of personnel categories. Referring to Tables I and II, it can be seen that labor classification B has been about the same magnitude for both laboratories. Hence, the

only ratios of concern are S/T and S/C. Thus, the formal statement of null hypothesis for each ratio is as follows:

1. The ratio of S/T for laboratory A is not significantly different from that for laboratory B.

2. The ratio of S/C for laboratory A is not significantly different from that for laboratory B.

At the time of comparison, moving averages of up to six quarters were being considered. Hence, Tables IV through IX were prepared and the two respective ratios compared. An appropriate test to use, according to Ostle (12), is Student's t-test. Although a sufficient number of points exist to use a normal test of differences, Student's t-test is less restrictive on the need to show normality. Further, the test is a determination that the difference between the two series being tested is not significantly different from zero. The statistic as computed is

$$t = \frac{\bar{D}}{SD} \sqrt{n - 1} \quad (1)$$

where

$$\bar{D} = \bar{B} - \bar{A} \quad (2)$$

and

$$SD = \sqrt{\sum (B_i - A_i - \bar{D})^2 / (n - 1)} \quad (3)$$

TABLE IV

KEY MANPOWER RATIOS BY QUARTERS FOR LABORATORIES
A AND B FOR A ONE-QUARTER MOVING AVERAGE

QTR	S/T-A	S/T-B	S/C-A	S/C-B
1	6.80000	6.68421	5.66666	5.29166
2	7.00000	5.52000	4.37500	5.75000
3	6.33333	5.41379	6.33333	6.03846
4	4.87500	6.43478	5.57142	5.28571
5	6.14285	5.10000	6.14285	4.92548
6	4.66666	6.25926	7.00000	5.63333
7	4.50000	5.19444	5.62500	5.84375
8	6.42857	5.54838	6.42857	5.21212
9	7.28571	5.70000	6.37500	5.56097
10	6.37500	5.70731	7.28571	5.57142
11	6.37500	5.70731	6.44444	4.85714
12	6.00000	6.71794	6.66666	5.45833
13	6.00000	7.18421	6.00000	5.93478
14	6.36363	6.92105	5.38461	5.84444
15	6.54545	6.61538	4.80000	5.86363
16	4.60000	5.40816	5.75000	5.52083
17	6.70000	7.07894	5.58333	5.38000
18	7.33333	5.85106	6.00000	5.97826
19	5.25000	5.62365	5.25000	6.73170
20	6.10000	6.56097	6.10000	6.56097
21	6.00000	5.37500	5.50000	6.29268
22	6.35353	6.04651	5.00000	6.19047
23	6.45454	5.84090	5.91666	5.97674
24	7.09090	6.00000	5.57142	6.00000
25	6.61538	6.00000	6.61538	6.00000
26	5.07142	5.92857	6.45454	5.92857
27	6.15384	5.25490	5.33333	6.53658
28	5.41176	5.53061	6.57142	6.30232
29	5.75000	5.97727	6.57142	6.11627
30	5.11111	6.27500	5.75000	6.60526
31	5.86666	6.30000	5.86666	7.00000
32	5.73333	6.86486	6.14285	6.68421
33	4.82353	6.71052	6.83333	6.21951
34	6.40000	7.02777	5.64705	7.02777
35	6.40000	7.17142	5.33333	7.17142
36	4.26086	6.55263	6.53333	7.11428
37	6.46666	5.70000	6.46666	6.70588
38	6.42857	5.84615	6.42857	6.90909
39	5.05263	5.86842	6.85714	6.96875
40	4.31818	5.91891	5.93750	7.06451

COMPUTED T = 1.03440

COMPUTED T = 0.68398

NUMBER OF DEGREES OF FREEDOM = 39

TABLE V
 KEY MANPOWER RATIOS BY QUARTERS FOR LABORATORIES
 A AND B FOR A TWO-QUARTER MOVING AVERAGE

QTR	S/T-A	S/T-B	S/C-A	S/C-B
1	6.90000	6.10210	5.02083	5.52083
2	6.66666	5.46689	5.35416	5.89423
3	5.60416	5.92428	5.95238	5.66208
4	5.50892	5.76739	5.85714	5.11059
5	5.40476	5.67963	6.57142	5.28440
6	4.58333	5.72685	6.31250	5.73854
7	5.46428	5.37141	6.02678	5.25793
8	6.85714	5.62419	6.40178	5.38654
9	6.83035	5.70365	6.83035	5.56620
10	6.08760	5.68699	6.86507	5.21428
11	5.90000	6.19230	6.55555	5.15773
12	6.00000	6.95107	6.33333	5.69655
13	6.18181	7.05263	5.69230	5.88961
14	6.45454	6.76821	5.09230	5.85404
15	5.57272	6.01177	5.27500	5.69223
16	5.65000	6.24355	6.55555	5.45041
17	7.01666	6.46500	5.79166	5.67913
18	6.29166	5.74185	5.62500	6.36498
19	5.67500	6.09681	5.67500	6.64634
20	6.05000	5.96798	5.80000	6.42682
21	6.18181	5.71075	5.25000	6.24158
22	6.40909	5.94371	5.45833	6.08361
23	6.77272	5.92045	5.74404	5.98837
24	6.85314	6.00000	6.09340	6.00000
25	5.84340	5.96428	6.53496	5.96428
26	5.61263	5.59173	5.89393	6.23257
27	5.78280	5.39275	5.95238	6.41945
28	5.58088	5.75394	6.57142	6.20930
29	5.43055	6.12613	6.16071	6.36077
30	5.48888	6.28750	5.80833	6.80263
31	5.80000	6.58243	6.00476	6.84210
32	5.27843	6.78769	6.48809	6.45186
33	5.61176	6.86915	6.24019	6.62364
34	6.40000	7.90960	5.49019	7.09960
35	5.33043	6.86203	5.93333	7.14285
36	5.36376	6.12631	6.50000	6.91008
37	6.44761	5.77307	6.44761	6.80748
38	5.74060	5.85728	6.64285	6.93892
39	4.68540	5.89367	6.39732	7.01663

COMPUTED T = 1.21665
 NUMBER OF DEGREES OF FREEDOM = 38

COMPUTED T = 0.74532

TABLE VI

KEY MANPOWER RATIOS BY QUARTERS FOR LABORATORIES
A AND B FOR A THREE-QUARTER MOVING AVERAGE

QTR	S/T-A	S/T-B	S/C-A	S/C-B
1	6.71111	5.87266	5.45833	5.69337
2	6.06944	5.78952	5.42658	5.69139
3	5.78373	5.64952	6.01587	5.41988
4	5.22817	5.93134	6.23809	5.28484
5	5.10317	5.51790	6.25595	5.47085
6	5.19841	5.66736	6.35119	5.56306
7	6.07142	5.48094	6.14285	5.53894
8	6.69642	5.65190	6.69642	5.44817
9	6.48690	5.69132	6.70171	5.32984
10	6.05833	6.03064	6.79894	5.29563
11	5.93333	6.52294	6.37036	5.41675
12	6.12121	6.52294	6.01709	5.74585
13	6.30303	6.90688	5.39487	5.88095
14	5.83636	6.31486	5.31153	5.74297
15	5.94848	6.36749	5.37777	5.58815
16	6.21111	6.11272	5.77777	5.62636
17	6.42777	6.18755	5.61111	6.02998
18	6.22777	6.01489	5.78333	6.42364
19	5.78333	5.85620	5.61666	6.52845
20	6.15454	5.99416	5.53333	6.34804
21	6.27272	5.75413	5.47222	6.15330
22	6.63636	5.92467	5.49603	6.05573
23	6.72027	5.94696	6.03449	5.99224
24	6.25924	5.97619	6.21378	5.97619
25	5.94688	5.27782	6.13442	6.15505
26	5.54567	5.57136	6.11976	6.25582
27	5.77187	5.58759	6.15873	6.31839
28	5.42429	5.92762	6.29761	6.34128
29	5.57592	6.18409	6.06269	6.57384
30	5.57036	6.47995	5.91984	6.76315
31	5.47450	6.62513	6.28095	6.63457
32	5.65228	6.86772	6.20774	6.64383
33	5.87450	6.96991	5.93790	6.80623
34	5.68695	6.91727	5.83790	7.10449
35	5.70917	6.47468	6.11110	6.99719
36	5.71870	6.03292	6.47618	6.90975
37	5.98262	5.80485	6.58412	6.86124
38	5.26646	5.87783	6.40773	6.98078

COMPUTED T = 1.49656
NUMBER OF DEGREES OF FREEDOM = 37

COMPUTED T = 0.68932

TABLE VII

KEY MANPOWER RATIOS BY QUARTERS FOR LABORATORIES
A AND B FOR A FOUR-QUARTER MOVING AVERAGE

QTR	S/T-A	S/T-B	S/C-A	S/C-B
1	6.25208	6.01319	5.48660	5.59146
2	6.08779	5.61714	5.60565	5.50214
3	5.50446	5.80195	6.26190	5.47324
4	5.04613	5.74612	6.08482	5.42457
5	5.43452	5.52552	6.28910	5.40617
6	5.72023	5.67552	6.25714	5.56254
7	6.14732	5.53753	6.42857	5.54706
8	6.47232	5.65559	6.63343	5.30041
9	6.36517	5.94798	6.69295	5.36196
10	6.04375	6.31903	6.59920	5.45542
11	6.04090	6.62246	6.12393	5.52367
12	6.22727	6.85964	5.71282	5.77529
13	5.87727	6.53220	5.48365	5.70992
14	6.05227	6.50588	5.37948	5.65222
15	6.29469	6.23838	5.53333	5.68568
16	5.97083	5.99270	5.64583	5.90269
17	6.34583	6.28090	5.73333	6.16273
18	6.17083	5.85492	5.71250	6.39090
19	5.92840	5.90378	5.46250	6.44396
20	6.22954	5.95584	5.62916	6.25521
21	6.47727	4.81560	5.49702	6.11497
22	6.63111	5.97185	5.77587	6.04180
23	6.30806	5.94237	6.13950	5.97632
24	6.23289	5.79586	5.99367	6.11628
25	5.81310	5.67852	6.24367	6.19186
26	5.59675	5.67283	6.23268	6.22093
27	5.60668	5.75944	6.05654	6.39011
28	5.53488	6.02072	6.18988	6.50596
29	5.61527	6.35428	6.08273	6.60143
30	5.38365	6.53759	6.14821	6.62724
31	5.70588	6.72579	6.12247	6.73287
32	5.83921	6.94364	5.98914	6.77573
33	5.47109	6.86559	6.08766	6.88325
34	5.88188	6.61295	5.99509	7.00484
35	5.88902	6.31755	6.19047	6.97517
36	5.55218	5.99180	6.57142	6.92450
37	5.56651	5.83337	6.42247	6.91205

COMPUTED T = 1.79687 COMPUTED T = 0.65334
NUMBER OF DEGREES OF FREEDOM = 36

TABLE VIII

KEY MANPOWER RATIOS BY QUARTERS FOR LABORATORIES
A AND B FOR A FIVE-QUARTER MOVING AVERAGE

QTR	S/T-A	S/T-B	S/C-A	S/C-B
1	6.23023	5.83055	5.61785	5.46026
2	5.80357	5.74556	5.88452	5.52859
3	5.30357	5.68045	6.13452	5.54734
4	5.32261	5.70737	6.15357	5.38208
5	5.80476	5.56-81	6.31428	5.43713
6	5.85118	5.68188	6.54285	5.56432
7	6.07785	5.56335	6.43174	5.40908
8	6.37785	5.86806	6.64007	5.33199
9	6.29214	6.19522	6.55436	5.47653
10	6.10772	6.43943	6.35628	5.53322
11	6.14181	6.62105	5.85914	5.59166
12	5.90181	6.56935	5.72025	5.72440
13	6.04181	6.64155	5.50358	5.70873
14	6.30848	6.37492	5.50358	5.71743
15	6.08575	6.11724	5.47666	5.89488
16	5.99666	6.10636	5.73666	6.03435
17	6.27666	6.08872	5.69666	6.18872
18	6.20939	5.89323	5.57000	6.35081
19	6.03363	5.89120	5.55333	6.35051
20	6.40181	5.96467	5.61761	6.20417
21	6.50489	5.85248	5.72069	6.09198
22	6.31918	5.96319	5.91160	6.01915
23	6.27722	5.80487	5.97827	6.08837
24	6.06866	5.74281	6.10922	6.15349
25	5.80048	5.73827	6.39022	6.17675
26	5.49962	5.79327	6.13614	6.29780
27	5.65876	5.86755	6.01857	6.51208
28	5.57457	6.18954	6.18047	6.54161
29	5.45692	6.42553	6.23285	6.52505
30	5.58692	6.63563	6.04798	6.70735
31	5.84470	6.81491	5.96464	6.82058
32	5.52354	6.86544	6.09798	6.84344
33	5.67021	6.63247	6.16274	6.84777
34	5.99122	6.45959	6.08179	6.98569
35	5.72174	6.22772	6.32380	6.97388
36	5.30538	5.97722	6.44464	6.95250

COMPUTED T = 1.96829

COMPUTED T = 0.63409

NUMBER OF DEGREES OF FREEDOM = 35

TABLE IX

KEY MANPOWER RATIOS BY QUARTERS FOR LABORATORIES
A AND B FOR A SIX-QUARTER MOVING AVERAGE

QTR	S/T-A	S/T-B	S/C-A	S/C-B
1	5.96964	5.90200	5.84821	5.48910
2	5.58630	5.65371	5.84126	5.58112
3	5.49107	5.64844	6.18353	5.49147
4	5.64980	5.70614	6.19047	5.41189
5	5.89980	5.58489	6.47619	5.45951
6	5.84265	5.67934	6.52645	5.44645
7	6.06488	5.75579	6.47089	5.41729
8	6.31488	6.08742	6.53339	5.43246
9	6.30405	6.31619	6.35940	5.53785
10	6.18068	6.46876	6.09690	5.58829
11	5.88484	6.41890	5.84095	5.57986
12	6.03484	6.65428	5.69743	5.66700
13	6.25706	6.50980	5.58632	5.75365
14	6.13206	6.25212	5.46132	5.88647
15	6.08813	6.19119	5.58055	6.00590
16	5.99722	5.98446	5.69722	6.07740
17	6.29116	6.09085	5.57222	6.18901
18	6.25052	5.88451	5.61777	6.28847
19	6.20984	5.90934	5.55634	6.29209
20	6.43741	5.97056	5.78391	6.17014
21	6.26598	5.86516	5.84300	6.06474
22	6.29162	5.84514	5.81522	6.10539
23	6.13297	5.75916	6.07713	6.12403
24	6.01555	5.78189	6.18625	6.14729
25	5.68558	5.82772	6.21601	6.24618
26	5.56080	5.87772	6.09123	6.41483
27	5.67111	6.03377	6.03928	6.54077
28	5.44939	6.27637	6.28928	6.48792
29	5.61410	6.52590	6.13522	6.60883
30	5.72243	6.72493	5.92887	6.78469
31	5.58073	6.77120	6.05943	6.86853
32	5.68073	6.67120	6.15942	6.83051
33	5.79660	6.50141	6.20504	6.85799
34	5.83478	6.36106	6.21101	6.98286
35	5.48781	6.17625	6.25942	6.98899

COMPUTED T = 2.14780

COMPUTED T = 0.65046

NUMBER OF DEGREES OF FREEDOM = 34

Referring to Tables IV through IX, the computed t value for moving averages of one through five quarters is seen to be less than the tabulated t value for 95-percent confidence (3). For a moving average of six quarters, it is less than the tabulated t value for 99-percent confidence, although it is greater than the tabulated t value for 95-percent confidence. Since a moving average over four quarters is used for the remaining analysis, the null hypotheses stated above are retained.

The fact that the B classifications were of the same magnitude merits some discussion. A closer review of the duties performed by these personnel disclosed the following summation by positions:

1. Chief, Administrative Office.
2. Personnel Specialist.
3. Technical Editor/Writer.
4. through 8. Program Analyst/Accountant.

Thus, it appears that this complement of personnel is largely independent of the size of the laboratory. Stated differently, it appears that over a broad range of total number of employees, a certain basic number of administrative specialists is required.

The Composite Output Variables

As noted in the preceding chapter, two types of reports produced by each laboratory exist. However, it was desirable to have a single measure of output. This suggested that some type of weighting factors was needed. In the earlier stages of this investigation, it was proposed to use the sum of the

two types of reports. This is, of course, equivalent to using a weighting factor of 1.0 for each report. Review of the official definition of each type of report, cited in the previous chapter, did not overtly imply that this was correct. However, the definition of an IN does imply a sense of urgency in making information available; this sense of urgency is lacking in the definition for a TM. After further consideration, it was decided to use a simple survey questionnaire (Appendix A) to further obtain insight into this matter. The results are presented in Tables X and XI. As is evident, it is unnecessary to resort to any elaborate statistical analysis to obtain the relative worth of the two types of reports. Opinion is remarkably homogenous for the two laboratories.

Thus, according to the manner in which the questionnaire was worded, the output variable, a composite of IN's and TM's, was defined as

$$P = 1.0 \text{ IN} + 1.0 \text{ TM} \quad (4)$$

which is the same as the originally proposed approach. Table III presents the output data for both laboratories; Table XII the same data and P as moving averages over four quarters. It is necessary to assume that the results of the survey hold true over the entire period of time represented by the data. This seems to be a safe assumption, for, of the responses received, 76 percent of the respondees have been with the Center for five years or longer. Thirty eight percent have been with the Center over 10 years.

TABLE X
RESULTS OF SURVEY QUESTIONNAIRE — LABORATORY A

Response Category	50/50	Ratio of IN/TM			10/90
		40/60	30/70	20/80	
<u>Position</u>					
Sr. Sci	1	2	2		1
Jr. Sci.	2	2	1	1	4
Engr.	11	1			
Manager	4	1	4		
<u>Age</u>					
20-25			1		1
26-30	3	2			3
31-35	4		1	1	1
36-40	2		2		
41-45	1	3			
46-50	4		2		
51-55	2	1	1		
Over 55	1				
<u>Education</u>					
Ph.D	3	2	3		1
MS	4	1	1		1
BS	11	3	3	1	3
<u>Grade</u>					
7					1
9			1		2
11	1	1		1	1
12	4	1	1	1	1
13	5	1	1		
14	5	1	1		
Over 14	3	2	3		
<u>Service</u>					
0-4	2	1	1	1	3
5-10	11	2	3		2
Over 10	5	3	2		

Response = 36%

TABLE XI
RESULTS OF SURVEY QUESTIONNAIRE — LABORATORY B

Response Category	Ratio of IN/TM				10/90
	50/50	40/60	30/70	20/80	
<u>Position</u>					
Sr. Sci.	9	3	4		1
Jr. Sci.	2				
Engr.	68	11	1	1	1
Manager	16	2	5	1	2
<u>Age</u>					
20-25	4	1			
26-30	20	1			1
31-35	26	5	1		1
36-40	19	6	2		
41-45	12	1	4	1	
46-50	6	1	2		1
51-55	4		1		1
Over 55	2	1		1	
<u>Education</u>					
Ph. D	3	2	1		1
MS	27	6	7		1
BS	65	8	2	2	2
<u>Grade</u>					
7	3	1			
9	3				
11	7				1
12	31	5	2		
13	32	5	3	1	1
14	10	4	1	1	1
Over 14	9	1	4		1
<u>Service</u>					
0-4	8	2			
5-10	50	8	3	1	1
Over 10	36	7	6	1	2

Response = 57%

TABLE XII
 REPORT OUTPUT AND COMPOSITE EQUIVALENT OUTPUT
 FOR LABORATORIES A AND B FOR A FOUR
 QUARTER MOVING AVERAGE

PD	IN-A	TM-A	P-A	IN-B	TM-B	P-B
1	6.00	18.00	24.00	4.50	7.00	11.50
2	6.50	17.25	23.75	3.50	7.25	10.75
3	8.00	17.50	25.50	4.25	8.00	12.25
4	7.75	21.50	29.25	4.25	8.50	12.75
5	7.75	21.25	29.00	4.50	7.75	12.25
6	8.75	21.25	30.00	3.75	7.25	11.00
7	9.50	20.50	30.00	4.00	8.50	12.50
8	10.00	16.50	26.50	5.50	8.00	13.50
9	10.25	14.75	25.00	6.00	9.00	15.00
10	10.75	12.00	22.75	6.50	9.50	16.00
11	10.50	12.75	23.25	6.00	9.00	15.00
12	11.00	13.00	24.00	6.00	8.75	14.75
13	10.25	14.25	24.50	7.25	7.50	14.75
14	8.75	15.50	24.25	5.50	7.50	13.00
15	8.25	14.75	23.00	6.25	8.50	14.75
16	6.25	15.75	22.00	5.25	9.25	14.50
17	5.50	18.50	24.00	4.50	9.50	14.00
18	5.75	19.00	24.75	5.00	11.00	16.00
19	6.25	19.50	25.75	4.25	10.00	14.25
20	6.25	16.25	22.50	4.75	9.25	14.00
21	6.75	18.50	25.25	5.00	9.50	14.50
22	6.75	18.75	25.50	5.00	10.00	15.00
23	6.75	18.50	25.25	5.00	9.00	14.00
24	5.75	19.25	25.00	6.25	11.00	17.25
25	4.50	20.50	25.00	6.00	10.75	16.75
26	4.00	19.00	23.00	6.00	9.75	15.75
27	4.50	17.50	22.00	6.50	10.25	16.75
28	4.50	16.50	21.00	6.50	10.75	17.25
29	5.50	16.00	21.50	6.00	11.25	17.25
30	5.25	15.50	20.75	6.50	10.00	16.50
31	3.75	14.25	18.00	5.75	11.25	17.00
32	4.50	15.50	20.00	5.75	11.00	16.75
33	4.50	14.50	19.00	6.75	9.00	15.75
34	4.25	16.25	20.50	5.75	10.00	15.75

The Regression Function

Two approaches may be taken in an attempt to find a relation between a given variable and a set of other variables. There are, according to Ezekiel and Fox (4), the use of correlation model or the use of a regression model. The mathematical manipulations are the same, being the well-known Gauss-Jordan method of least squares. However, the correlation model requires the assumption that the data used, besides being normally distributed, comprise a sample from the universe at large. The regression model requires no such assumption. Normality, as such, is also not required, although the distribution of error about the dependent variable is assumed to be normally and independently distributed. However, the regression model requires that any conclusions drawn from the use of the model be limited strictly to the conditions from which the model was derived. It was concluded that the regression model is more suitable for the ensuing analysis. A detailed description of the mechanics of regression is not presented, since this is widely available in the literature. However, the specific computer program, REGR, used is given in Appendix B. It is particularly useful, in that by use of the listed subroutine DATA, the variables can be suitably transformed and/or manipulated as desired by the user.

This was essential, although there is a relatively small number of variables, it was the first objective of this study to find a satisfactory relation between input and output. The variables, as transformed and used, which were finally selected were S/T, S/C, and $\ln n$. These were arrived at by

using variables and lags from the first 24 data points from Table II. These are shown in Table XIII. The available evidence from previous studies, as discussed in Chapter I, suggested that a multiplicative model would be obtained (alternatively, logarithmic transformation would be required). Thus, the regression analyses shown in Table XIV were obtained. The test of significance that was used is again Student's t-test. In this case, the three formally stated null hypotheses to be tested are:

1. The regression coefficient for $\ln (S/T)$ is not significantly different from zero (denoting no relation between P and S/T).
2. The regression coefficient for $\ln (S/C)$ is not significantly different from zero (denoting no relation between P and S/C).
3. The regression coefficient between P and $\ln n$ is not significantly different from zero (denoting no relation between P and $\ln n$).

The number of degrees of freedom is $n - M - 1$, where n is the number of data points and M the number of independent variables. Thus, for 24 data points and three independent variables, $NDF = 20$. The tabulated t value is 2.086. Hence, all three null hypotheses are rejected at the five percent level. It is concluded that the obtained coefficients represent a good relation between input and output.

Thus, the obtained regression equation is

$$\ln P = 1.98 - 0.85 \ln S/T - 0.82 \ln S/C + 2.38 \ln (\ln n) \quad (5)$$

which is equivalent to

TABLE XIII

LABORATORY B VARIABLES USED IN REGRESSION ANALYSIS

T	C	B/P	S	P	S/T	S/C	LN N
26.74	30.24	1.99	148.99	23.99	5.57	4.92	5.33
27.24	31.49	1.99	156.74	23.74	5.75	4.97	5.38
28.99	33.99	1.99	164.24	25.49	5.66	4.83	5.43
30.99	36.99	1.99	170.24	29.24	5.49	4.60	5.48
33.49	41.24	2.25	188.99	28.99	5.64	4.58	5.58
36.99	44.99	2.50	205.24	29.99	5.54	4.56	5.66
38.49	46.24	2.99	217.99	29.99	5.66	4.71	5.72
40.49	46.99	3.49	240.50	26.49	5.93	5.11	5.80
39.99	45.74	3.74	251.74	24.99	6.29	5.50	5.83
39.24	45.74	3.99	258.99	22.74	6.59	5.66	5.85
38.49	46.74	4.24	263.99	23.24	6.85	5.64	5.86
40.99	46.99	4.49	264.74	23.99	6.45	5.63	5.87
40.99	46.24	4.99	263.74	24.49	6.43	5.70	5.87
43.24	44.49	5.49	266.74	24.24	6.16	5.99	5.88
45.74	42.24	5.74	271.24	22.99	5.92	6.42	5.89
43.74	41.24	5.99	272.24	21.99	6.22	6.59	5.89
46.24	41.74	5.99	269.49	23.99	5.82	6.45	5.89
45.24	42.24	5.99	265.74	24.74	5.87	6.28	5.88
43.99	43.49	5.99	260.99	25.74	5.93	5.99	5.87
45.49	43.49	5.74	258.24	22.49	5.67	5.93	5.86
43.99	42.99	5.49	262.74	25.24	5.97	6.11	5.87
43.74	42.99	5.24	259.99	25.49	5.94	6.04	5.86
45.49	42.24	4.99	262.74	25.24	5.77	6.21	5.87
46.99	41.24	4.99	265.99	24.99	5.65	6.44	5.88

TABLE XIV

RESULTS OF REGRESSION ANALYSIS ON LABORATORY B VARIABLES

Variable No.	Mean	Standard Deviation	Correlation X vs. Y	Regression Coefficient	Std. Error of Regr. Coeff.	Computed T
ln (S/T)	1.78226	0.05929	-0.54342	-0.85062	0.17165	-4.95540
ln (S/C)	1.71990	0.12304	-0.68909	-0.82093	0.11187	-7.33787
ln (ln n)	1.75169	0.03223	-0.34212	2.37888	0.46974	5.06420

Dependent

ln (P) 3.22301 0.08738

Intercept = 1.98389 Multiple Correlation = 0.89999 Std. Error of Estimate = 0.04084

$$P = 3.64 (S/T)^{-0.85} (S/C)^{-0.82} (\ln n)^{2.38} \quad (6)$$

Ezekiel and Fox (4) recommended an investigation of the partial coefficients of correlation as a normal part of regression analyses. The partial coefficient of correlation is defined as follows:

$$r_{12 \cdot 34}^2 = 1 - \frac{1 - r_{1 \cdot 234}^2}{1 - r_{1 \cdot 34}^2} \quad (7)$$

where $r_{1 \cdot 234}$ is the multiple regression coefficient between variable 1 and variables 2, 3, and 4, and $r_{1 \cdot 34}$ is the multiple regression coefficient between variable 1 and variable 3 and 4.

In effect, the partial coefficient of correlation indicates the strength of the relationship between variables 1 and 2, with variables 3 and 4 held constant. The advantage of using partial correlation coefficients is that any intercorrelations between the independent variables are removed. Alternatively, a simple regression between variables 1 and 2 could very well indicate little or no relation between them when in fact there may be quite a strong relation. Table XV presents the results of considering the partial correlation coefficients. It can be seen that all three factors are quite strongly related to the output variable, whereas the simple correlation coefficients in Table XIV (which represent the simple regression of output upon each of the three independent variables without considering the remaining other two variables) indicate a less strong relationship.

TABLE XV

RELATIVE IMPORTANCE OF INDIVIDUAL FACTORS
AFFECTING OUTPUT (P) AS INDICATED BY
COEFFICIENTS OF PARTIAL CORRELATION

Factors Already Considered	Factor Added	Coefficient of Partial Correlation	Reduction in Unexplained Variance
S/T, ln n	S/C	0.914	0.833
S/T, S/C	ln n	0.751	0.562
S/C, ln n	S/T	0.744	0.552

Validation

The question naturally arises in the use of regression analysis as to how to validate the obtained relation. As indicated previously, there are two approaches that can be taken. One is to take another series of data and re-perform the regression analysis. If the postulated relationship holds, the second expression will not be significantly different from the initial expression. The second approach is to take data from a postulated similar organization and perform a regression analysis. Again, the results of this second analysis should not be significantly different. Unfortunately, there are many regression lines (or hyperplanes, in the case of multiple regression) which can be found for any set of data, only one of which is determined by the method of least squares. Thus, it is theoretically possible to obtain a regression line or hyperplane from one set of data which, when tested against that

from a second set, does not appear to hold for the second set. However, it must be remembered that the purpose of obtaining a regression expression is ultimately for use in prediction. (Again, it is recalled from Ostle (12) that it is not necessary to assume causality for prediction purposes.) It is therefore sufficient to use the obtained regression function to predict dependent variables from a second set of independent variables. If the predicted variables do not differ significantly from the observed variables, then this is considered to be satisfactory for validating the model as a predictive tool.

Before validation was attempted, however, it was necessary to perform one other test on the results of the regression analysis. This was to test for the presence of autocorrelation. Such a test was necessary to check the assumption that time is, in fact, a passive medium for the data series used. The consequences of this not being true is that a regression analysis performed upon autocorrelated data yields less information than one performed upon data with no autocorrelation; e.g., if the data set of twenty-four points were autocorrelated, it would provide the same information as a non-autocorrelated set of thirteen points. Ezekiel and Fox (4) recommend a test upon the residuals, for if autocorrelation were present in any of the variables, it will be detected in the residuals. (The residuals are the differences between the observed and predicted values of the dependent variable.) The appropriate test on the residuals is von Neumann's ratio, which is defined as

$$\frac{\sum (X_i - X_{i+1})^2 / (n - 1)}{\sum X_i^2 / n}$$

where X_i represents the residual values. Comparison of the calculated value of 2.53 with the tabulated limits of 1.41 and 2.76, respectively, for the five percent limits for positive and negative autocorrelation, permits retention of the null hypothesis; i.e., formally stated, there is no significant autocorrelation in the data.

It should be noted that this does not mean that one cannot obtain runs of increasing or decreasing values in any of the data sets. Rather, it means that such runs, if present, are not related to the passage of time or that a succeeding value is not dependent upon the value of a preceding data point. It should also be noted that the computed t value presented by Table XVI has no meaning here, since the estimated values were obtained from the set of data which provided the observed values. However, the computer program which was used in the subsequent tests was utilized for this set of data to obtain von Neumann's ratio.

Thus, with no reason to suspect any autocorrelation, the next step was to validate the obtained expression. Both approaches just described were used. First, the remaining input data points from laboratory B were used for predicting P . These were compared to the observed output values (Table XVII). The hypothesis being tested is that there is no significant difference between observed and predicted values; i.e., the difference between them is not significantly different from zero. Again, Student's t -test is used. The tabulated value of t for 95 percent confidence is 2.62; since the computed value of 1.96 is less than the tabulated value, the null hypothesis is retained.

TABLE XVI

COMPARISON OF OBSERVED VALUES OF LABORATORY B OUTPUT
WITH THOSE ESTIMATED BY THE REGRESSION EQUATION

OBSERVED OUTPUT		ESTIMATED OUTPUT		RESIDUAL	
LN P	P	LN P	P	LN D	D
3.178	(23.99)	3.198	(24.48)	-0.020	(-0.48)
3.167	(23.74)	3.182	(24.10)	-0.014	(-0.35)
3.238	(25.49)	3.242	(25.60)	-0.004	(-0.10)
3.375	(29.24)	3.329	(27.92)	0.046	(1.32)
3.367	(28.99)	3.353	(28.61)	0.013	(0.38)
3.401	(29.99)	3.408	(30.20)	-0.006	(-0.20)
3.401	(29.99)	3.386	(29.55)	0.015	(0.44)
3.277	(26.49)	3.311	(27.42)	-0.034	(-0.92)
3.218	(24.99)	3.214	(24.88)	0.004	(0.11)
3.124	(22.74)	3.158	(23.54)	-0.034	(-0.79)
3.146	(23.24)	3.135	(22.97)	0.011	(0.27)
3.178	(23.99)	3.191	(24.33)	-0.013	(-0.33)
3.198	(24.49)	3.183	(24.13)	0.015	(0.36)
3.188	(24.24)	3.182	(24.11)	0.005	(0.13)
3.135	(22.99)	3.165	(23.70)	-0.030	(-0.70)
3.091	(21.99)	3.100	(22.19)	-0.008	(-0.19)
3.208	(24.74)	3.184	(24.15)	0.024	(0.59)
3.248	(25.74)	3.209	(24.75)	0.039	(0.99)
3.113	(22.49)	3.263	(25.88)	-0.140	(-3.38)
3.228	(25.24)	3.189	(24.27)	0.039	(0.97)
3.238	(25.39)	3.198	(24.49)	0.040	(1.00)
3.228	(25.24)	3.203	(24.62)	0.025	(0.62)
3.218	(24.99)	3.195	(24.41)	0.023	(0.58)
3.178	(23.99)	3.174	(23.91)	0.003	(0.08)

COMPUTED T = -0.00079
DEGREES OF FREEDOM = 23

VON NEUMANN'S RATIO = 2.53552

TABLE XVII
 COMPARISON OF OBSERVED VALUES WITH THOSE
 ESTIMATED FROM THE REGRESSION EQUATION

OBSERVED OUTPUT		ESTIMATED OUTPUT		RESIDUAL	
LN P	P	LN P	P	LN D	D
3.218	(24.99)	3.176	(23.95)	0.042	(1.04)
3.135	(22.99)	3.136	(23.02)	-0.001	(-0.02)
3.091	(21.99)	3.090	(21.99)	0.000	(0.00)
3.044	(20.99)	3.037	(20.85)	0.006	(0.14)
3.068	(21.49)	3.008	(20.25)	0.059	(1.24)
3.032	(20.74)	2.893	(18.06)	0.138	(2.68)
2.890	(17.99)	2.964	(19.39)	-0.074	(-1.39)
2.995	(19.99)	2.887	(17.95)	0.107	(2.04)
2.944	(18.99)	2.946	(19.01)	0.000	(0.00)
3.020	(20.49)	2.918	(18.50)	0.102	(1.99)
COMPUTED T = -1.86385 DEGREES OF FREEDOM = 9					
VON NEUMANN'S RATIO = 2.38276					

The next question to be answered was whether the obtained expression would be satisfactory for predicting the output of laboratory A. The results are shown in Table XVIII, using all the data points from laboratory A. The null hypothesis is again that the residuals are not significantly different from zero. The computed value of 1.60 compared to the tabulated value of 2.04 for 95 percent confidence indicated that this hypothesis could be retained. As a matter of course, von Neumann's ratio was calculated for the latter two sets of residuals. The critical limits (for 95 percent confidence) for the first set are 1.18 and 3.26, respectively, as compared to the calculated value 2.29. For the second set (Table XVIII), the critical limits are 1.50 and 2.63, respectively, as compared to the calculated value of 2.24. Thus, no reason to suspect the existence of autocorrelation is found for either of these two sets of residuals. Thus, the obtained regression expression of equation (6) was taken to be valid under the circumstances described; i. e., this expression is considered to represent the relation between input and output for the research laboratories A and B for predictive purposes. The first objective of the study has been achieved.

It should be noted that to be rigorous in application of the foregoing tests on the residuals, it was necessary to use the transformed data as used in the regression analysis, rather than the tabulated untransformed variables. For convenience, Tables XVI, XVII, and XVIII show both the logarithm and the corresponding untransformed value.

The final step was to establish confidence limits for an individual estimate. These are determined from the present inherent error. There are

TABLE XVIII
 TEST FOR AUTOCORRELATION ON RESIDUALS
 FROM LABORATORY A DATA

OBSERVED OUTPUT		ESTIMATED OUTPUT		RESIDUAL	
LN P	P	LN P	P	LN D	D
2.442	(11.49)	2.357	(10.56)	0.085	(0.93)
2.374	(10.74)	2.436	(11.43)	-0.061	(-0.68)
2.505	(12.24)	2.533	(12.59)	-0.027	(-0.34)
2.545	(12.74)	2.493	(12.10)	0.051	(0.64)
2.397	(10.99)	2.436	(11.43)	-0.039	(-0.43)
2.525	(12.49)	2.457	(11.67)	0.068	(0.82)
2.602	(14.39)	2.584	(13.25)	0.018	(0.24)
2.505	(12.24)	2.468	(11.80)	0.036	(0.44)
2.708	(14.99)	2.706	(14.98)	0.001	(0.01)
2.772	(15.99)	2.727	(15.28)	0.045	(0.71)
2.708	(14.99)	2.681	(14.60)	0.026	(0.39)
2.691	(14.74)	2.704	(14.95)	-0.013	(-0.20)
2.691	(14.74)	2.636	(13.96)	0.054	(0.78)
2.564	(12.99)	2.581	(13.21)	-0.016	(-0.21)
2.691	(14.74)	2.654	(14.08)	0.046	(0.66)
2.674	(14.49)	2.637	(13.97)	0.036	(0.52)
2.639	(13.99)	2.664	(14.36)	-0.025	(-0.36)
2.772	(15.99)	2.757	(15.76)	0.014	(0.23)
2.656	(14.24)	2.716	(15.13)	-0.060	(-0.88)
2.639	(13.99)	2.609	(13.58)	0.029	(0.41)
2.674	(14.49)	2.614	(13.65)	0.060	(0.84)
2.708	(14.99)	2.668	(14.41)	0.039	(0.58)
2.639	(13.99)	2.680	(14.59)	-0.041	(-0.59)
2.847	(17.24)	2.796	(16.39)	0.050	(0.85)
2.818	(16.74)	2.818	(16.75)	0.000	(0.00)
2.756	(15.74)	2.796	(16.38)	-0.039	(-0.63)
2.818	(16.74)	2.766	(15.90)	0.051	(0.84)
2.847	(17.24)	2.777	(16.08)	0.070	(1.16)
2.847	(17.24)	2.872	(17.68)	-0.024	(-0.43)
2.803	(16.49)	2.826	(16.89)	-0.023	(-0.39)
2.833	(16.99)	2.838	(17.09)	-0.005	(-0.09)
2.818	(16.74)	2.865	(17.55)	-0.046	(-0.80)
2.756	(15.74)	2.735	(15.42)	0.021	(0.32)
2.756	(15.74)	2.754	(15.71)	0.002	(0.03)

COMPUTED T = -1.61277
 DEGREES OF FREEDOM = 33

VON NEUMANN'S RATIO = 2.25933

three components to this error, according to Ezekiel and Fox (4): (1) the error about the dependent variable, (2) the error along the regression plane, and (3) the error about the regression plane. Thus, an individual estimate of y' , referred to the mean instead of the origin, is

$$y' = \bar{y} + b_1(X_1 - \bar{X}_1) + b_2(X_2 - \bar{X}_2) + b_3(X_3 - \bar{X}_3). \quad (8)$$

The expected deviation is

$$S_{y'} = \left(S_y^2 + \frac{S_y^2}{n} + (X_1 - \bar{X}_1)^2 S_{b_1}^2 + (X_2 - \bar{X}_2)^2 S_{b_2}^2 + (X_3 - \bar{X}_3)^2 S_{b_3}^2 \right)^{1/2} \quad (9)$$

where

$$S_{b_i} = \frac{SE}{nS_{X_i}} \quad (10)$$

Simplifying, then,

$$S_{y'} = SE \left(1 + \frac{1}{n} \left(1 + \frac{(X_1 - \bar{X}_1)^2}{nS_{X_1}^2} + \frac{(X_2 - \bar{X}_2)^2}{nS_{X_2}^2} + \frac{(X_3 - \bar{X}_3)^2}{nS_{X_3}^2} \right) \right)^{1/2} \quad (11)$$

so that the confidence limits for an individual estimate of the dependent variable is

$$y' \pm t_{\alpha} S_{y'}$$

Combining equations (8) and (11), using the tabulated t value for 95-percent confidence and expressing the results in terms of the variables used earlier,

the following is obtained:

$$\begin{aligned}
 \ln P \pm 0.95 &= \overline{\ln P} + b_1 (\ln S/T - \overline{\ln S/T}) + b_2 (\ln S/C - \overline{\ln S/C}) \\
 &\quad + b_3 (\ln \ln n - \overline{\ln \ln n}) \\
 &= \pm 2.080 S_{\ln P}
 \end{aligned} \tag{12}$$

where

$$\begin{aligned}
 S_{\ln P} = \text{SE} &\left(1 + \frac{1}{n} \left(1 + \frac{(\ln S/T - \overline{\ln S/T})^2}{nS^2_{\ln S/T}} + \frac{(\ln S/C - \overline{\ln S/C})^2}{nS^2_{\ln S/C}} \right. \right. \\
 &\quad \left. \left. + \frac{(\ln \ln n - \overline{\ln \ln n})^2}{nS^2_{\ln \ln n}} \right) \right)^{1/2}
 \end{aligned} \tag{13}$$

In this case, it was necessary to use the transformed variables, since they were the basis of the obtained regression expression. Thus, the predicted value of P and both the upper and lower prediction limits are obtained first as transformed values. The real-life predicted values and associated prediction limits must be obtained from an inverse transformation to present the predicted values in useful form.

CHAPTER IV

APPLICATION

Program STAFF

Any regression function, with appropriate confidence limits, is useful only when applied. The regression function obtained in Chapter III was applied in an evaluation program, STAFF, to determine how output of a research organization might vary according to labor budget fluctuations and various staffing options. The specific options of interest, which were discussed in Chapter I, are summarized in Table XIX. The immediate problem which was faced was one of transforming the regression results and the four options into a suitable FORTRAN computer program. This approach was selected, since it appeared to be the most convenient method of handling the somewhat complicated calculations of predicted output and associated prediction limits, as well as handling the other required manipulations. The general program is depicted in Figure 5. The detailed FORTRAN program is presented in Appendix C. To appreciate its operation, it is necessary to discuss several of the more important features which have been provided.

First, because of the approach taken in obtaining the regression equation, a condition had to be set up which would permit duplication of this approach in the program. This meant that, for the period of time for

TABLE XIX

SUMMARY OF OPTIONS USED IN PREDICTION MODEL

Option	Description
1	Reduce or increase personnel levels by a fixed percentage based upon the difference between projected budget and budget required to maintain current levels.
2	Reduce or increase personnel levels for the ensuing year, maintaining or improving the S/T, S/C ratios.
3	Reduce personnel levels by a proportionate amount on a quarter-by-quarter basis until required reduction is obtained.
4	Reduce levels on a quarter-by-quarter basis while maintaining or improving S/T, S/C ratios.

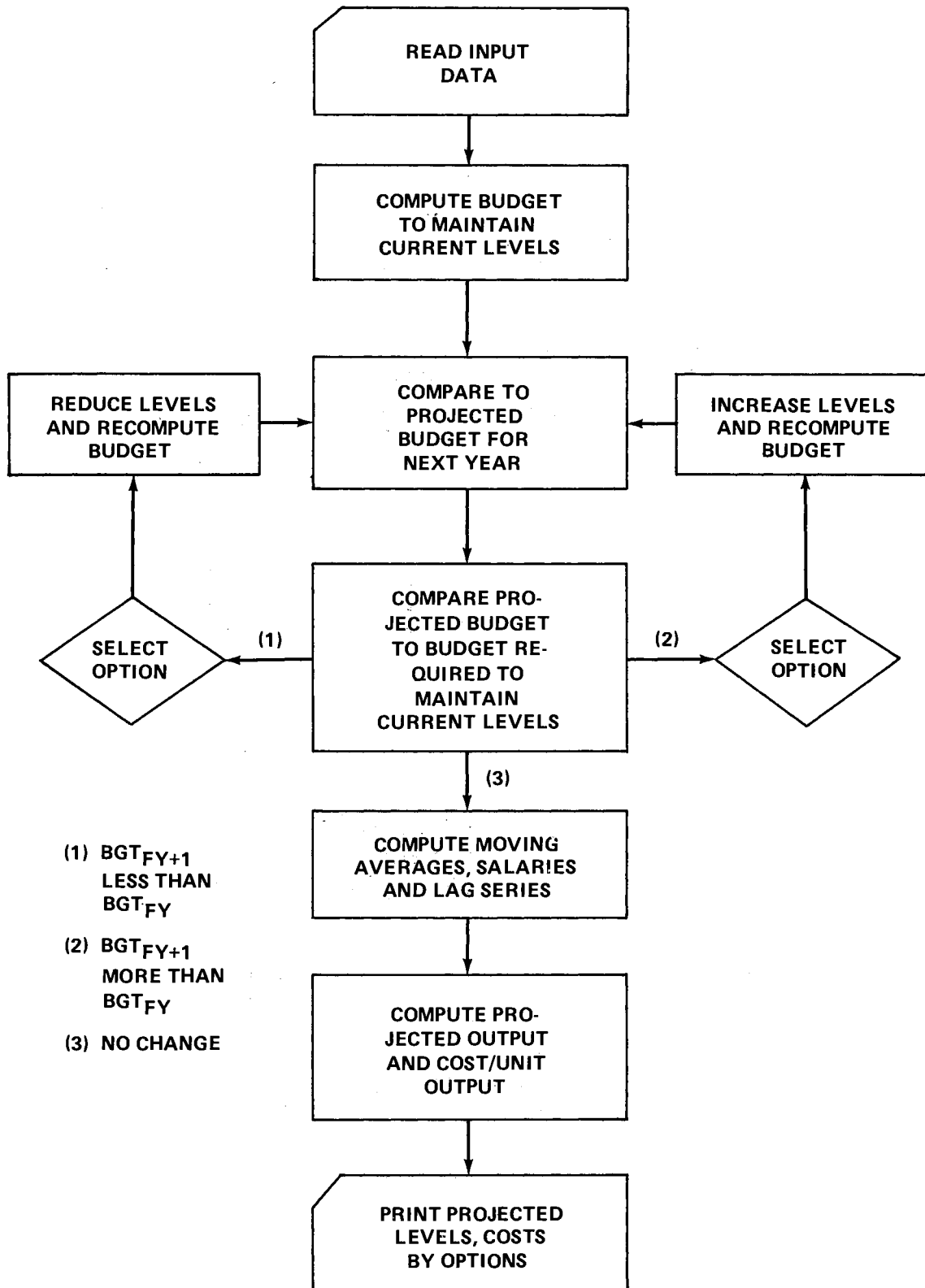


Figure 5. Simplified Flow Chart for Program STAFF.

which staffing levels would be predicted, appropriate lags and moving averages had to be established before using the regression function and its prediction limits. The rationale used was as follows. The quarterly staffing levels of the current year were taken as part of the input. The average annual salary for each skill classification was also taken as input. The salaries and staffing levels were used to compute the labor budget required to maintain the current staffing level; i.e., the level of the fourth quarter of the current year. The levels for the ensuing year were also set equal to the level of the fourth quarter. The computation of the budget required to maintain current staffing levels includes an inflation factor in recognition of the decreasing purchasing power of funds as a result of inflation and promotions. In this application, a factor of 0.06 was used for all cases.

Next, it was necessary to test the value of the required budget against the value of the projected budget for the ensuing year. If the two values are the same, the staffing levels are stable and the program will proceed to perform the foregoing operations for the second ensuing year. If the two values are unequal, the program then will reduce or increase, as appropriate, the staffing levels according to instructions provided by each of the four options. The program does this automatically, although it is possible to modify it for a particular option only. Upon completion of this procedure for each successive year, the program then takes moving averages of each input series of data, lags the series appropriately and then performs the prediction functions, using as fixed program values the results obtained from the regression

analysis of Chapter III. These values also can be modified if conditions warrant without destroying any of the other features of the program.

Because it appeared that the levels of the B skill classification might be determined by management decisions independent of levels of T, C, or S, provision was incorporated for changing these levels independently of any of the options. Thus, for example, the B level could be increased during a period of decline or it could be decreased during a growth period. (The observation that the B levels may be determined separately is based upon the fact that no ratio was found in which B appeared, nor did any of the various regressions performed show a significant relation between it and the output.)

As indicated by Table XIX, options one and two increase or decrease the staffing levels proportionally to the change in the projected budget. Options three and four, however, use a step-wise approach in reducing the staffing levels. This required the use of a computation factor. A value of 0.01 was arbitrarily chosen, but because it might be desirable to use another factor, provision was made for the user to vary this as desired. The only restriction on this factor is that if too large a value is used (values over 0.1, for example), the program will not yield meaningful results for small budget changes.

Up to 10 years' budget projections may be accommodated by the program as written, although four or five years are the most that are generally projected by organizations such as NASA. Both the number of years being projected and the projected budgets for those years must be entered as input.

The values of the ratios S/T and S/C that are desired to be attained are also required as input. For ease of programming, these remain constant over the projected period of time.

Output of the program consists of a set of three tables for each of the four options. The first table compares the projected budget for each successive year with the budget required to maintain staffing levels at the current level of the preceding year. The second table lists the projected staff levels for each of the skill classifications. The third and final table provide the attained S/T and S/C ratios, predicted output, the upper and lower prediction limits, and the total labor cost per unit output. The program may use a special subroutine, PLOT, to chart the predicted output and confidence limits for each option. After all four options are tabulated and charted, PLOT may also be used to chart output of each option against time on a single graph. A similar chart is prepared for total cost per report against time.

It should be noted that additional options can be accommodated simply by adding the additional statements and by suitable modification to the appropriate branching statement in the program. It is noted that besides the regression function being changed, the moving average and lag factors could be modified to accommodate any other values which the user might desire.

The input data for each of the four cases summarized in the following discussion are listed in Appendix D. The format indicated by this listing must

be followed in using the program unless the input format statements are altered approximately. In summary, it is believed that a high degree of flexibility has been provided so that the program could be used for a variety of situations, in addition to the specific applications presented here. Attention is called to the fact that STAFF, as well as the other programs used for this study, has been written for the IBM 1130 computer, using FORTRAN IV. STAFF and the other programs may be used with any other machine having a FORTRAN IV compiler simply by modifying the input/output instructions in the programs.

Cases I, II, and III

In Chapter II, the general hypothesis was stated to the effect that, of the several options available to the research manager, one might be better under a growth situation, while another might be more satisfactory under a condition of decline. In view of the regression function obtained in Chapter III, which included the parameters S/T and S/C, the formally stated hypotheses evaluated in this Chapter were:

- (1) For a growth situation, option two is the best staffing option for both total output and effective cost per report.
- (2) For decline situation, option four is the best for both output and effective cost per report.

These hypotheses were evaluated by using the input data described in the preceding section, under the following conditions:

- (1) Case I: Projected budget increased each year by 10 percent.

(2) Case II: Projected budget decreased each year by 10 percent.

(3) Case III: Projected budget alternately increased and decreased each year by 10 percent.

In addition, each case was projected over five fiscal years under the following situations:

- (1) High S/T, high S/C.
- (2) Low S/T, low S/C.
- (3) Average S/T, average S/C.
- (4) High S/T, low S/C.
- (5) Low S/T, high S/C.

The specific values for S/T and S/C were taken from Table VII, where "high" was the maximum value of S/T, "low" was the minimum value, and "average" was the mean value. The data set for both laboratories A and B (and all four cases) are listed in Appendix D. A partial listing of Program STAFF output for Cases I, II, and III is presented in Appendix E. A summary of results is given in Tables XX and XXI, with the indicated staffing option for the individual conditions given in Table XXII. Based upon these results, it appeared that the two hypotheses stated above could be retained. It is noteworthy that for some particular situations, such as both the S/T and S/C ratios being "high," one of the other options might be the better choice.

The projected output for options two and four, under several conditions, has been graphically illustrated in Figures 6 through 17 for both laboratories A and B. These figures provide an indication as to how sensitive output is to the staffing ratios S/T and S/C. It appeared that output is

TABLE XX
 SUMMARY OF OUTPUT FROM PROGRAM STAFF
 LABORATORY A

S/T	S/C	Option	Case I	Case II	Case III
High	High	1	*		
		2	\$		
		3			*, \$
		4		*, \$	
Low	Low	1			
		2	*, \$		
		3			
		4		*, \$	
Avg	Avg	1			
		2	*, \$		
		3			
		4		*, \$	*, \$
High	Low	1	*, \$		
		2			
		3			
		4		*, \$	*, \$
Low	High	1	*		\$
		2			
		3			*
		4		*	

TABLE XXI
 SUMMARY OUTPUT FROM PROGRAM STAFF
 LABORATORY B

S/C	S/T	Option	Case I	Case II	Case III
High	High	1	*		
		2	\$		*
		3		*	
		4			
Low	Low	1			
		2	*, \$		
		3			
		4	*, \$		*
Avg	Avg	1			
		2	*, \$		
		3			
		4		*, \$	*
High	Low	1			
		2	*, \$		
		3			
		4		*, \$	*, \$
Low	High	1			
		2	*, \$		\$
		3			
		4		*	*

TABLE XXII

INDICATED STAFFING OPTION BASED UPON
PROGRAM STAFF PROJECTIONS

S/T	S/C	Case I	Case II	Case III
High	High	1	4	3
Low	Low	2	4	2, 4
Avg	Avg	2	4	4
High	Low	2	4	4
Low	High	2	4	3, 4

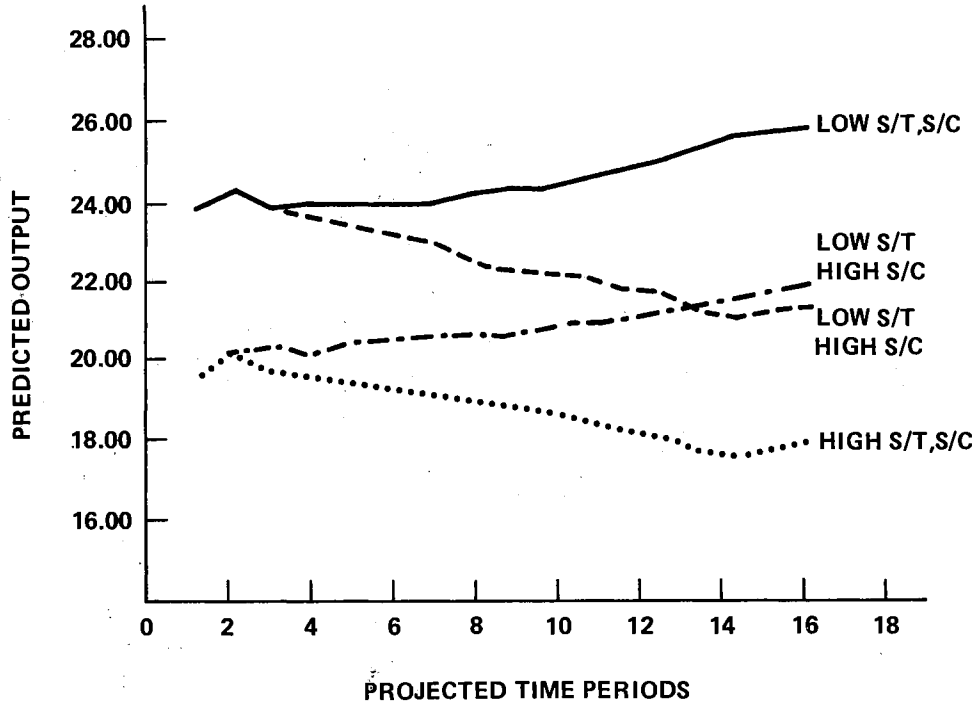


Figure 6. Laboratory A Predicted Output, Option Two, Case I.

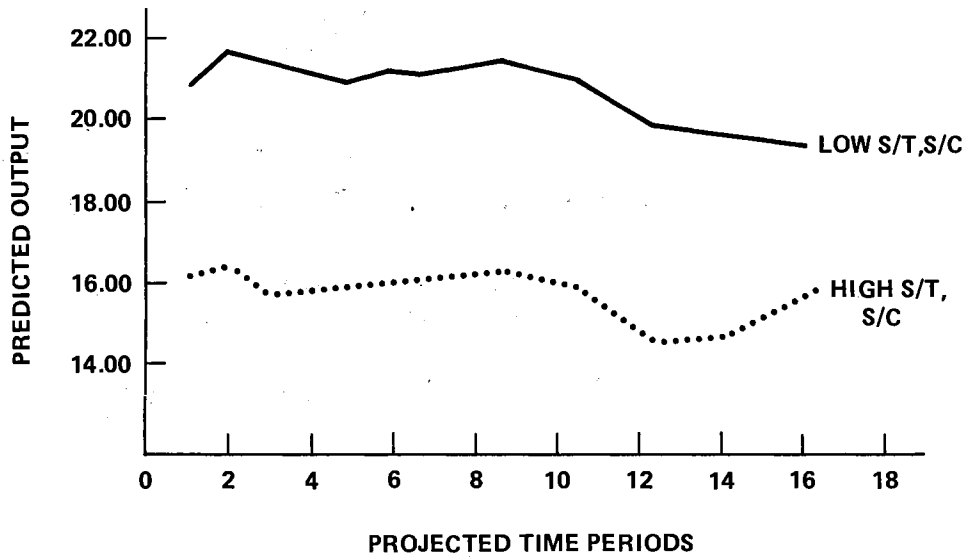


Figure 7. Laboratory A Predicted Output, Option Two, Case II.

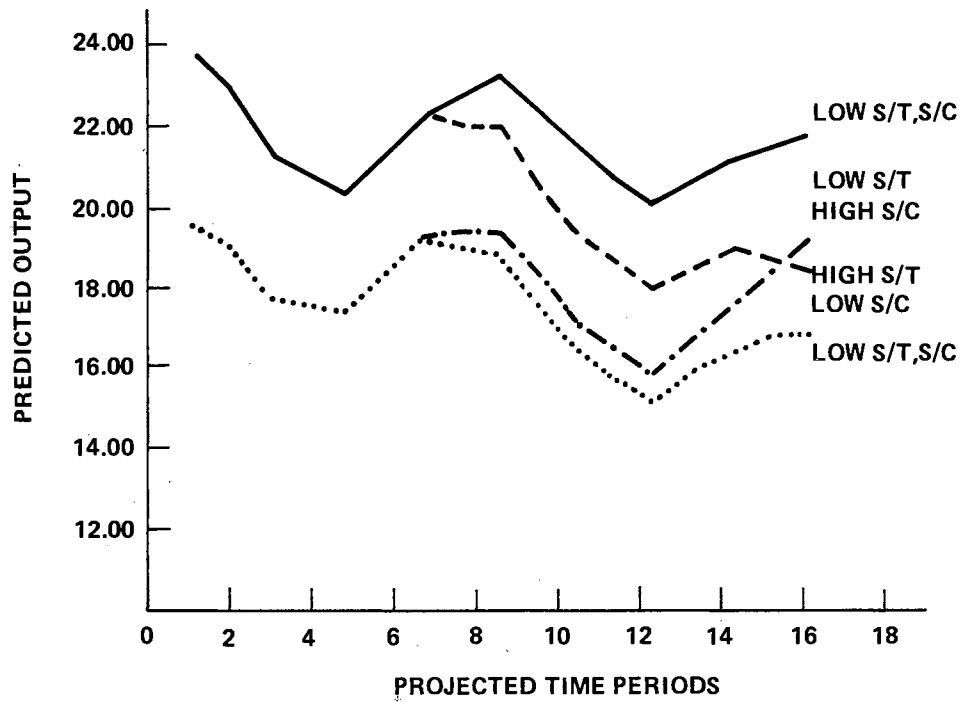


Figure 8. Laboratory A Predicted Output,
Option Two, Case III.

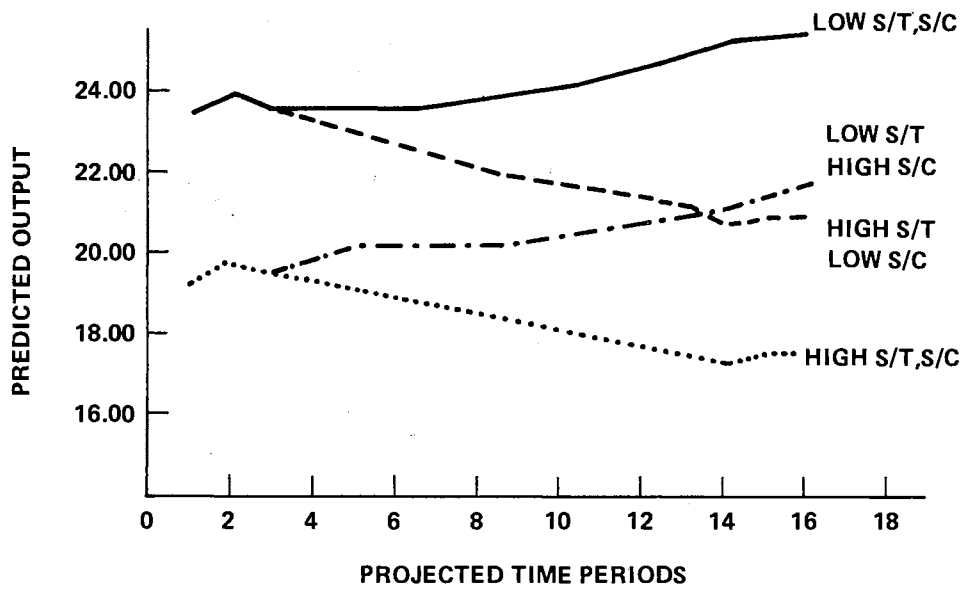


Figure 9. Laboratory A Predicted Output,
Option Four, Case I.

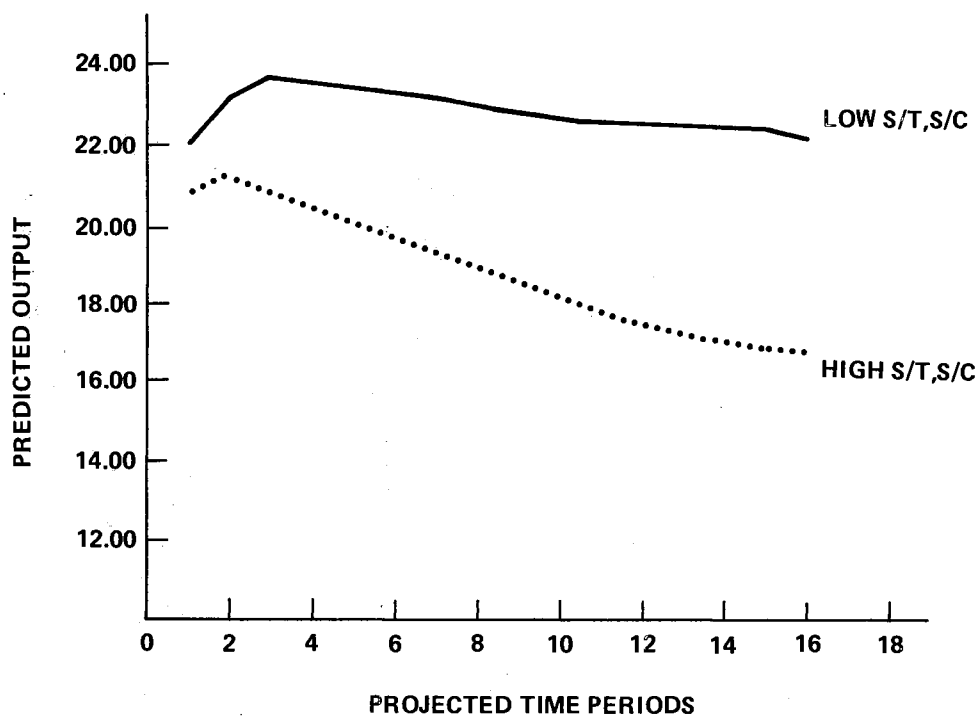


Figure 10. Laboratory A Predicted Output,
Option Four Four, Case II.

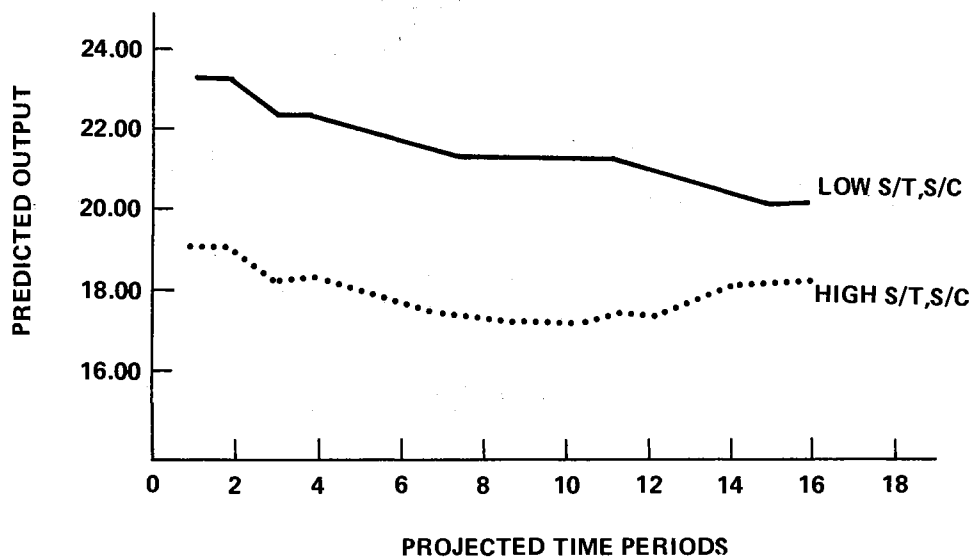


Figure 11. Laboratory A Predicted Output,
Option Four, Case III.

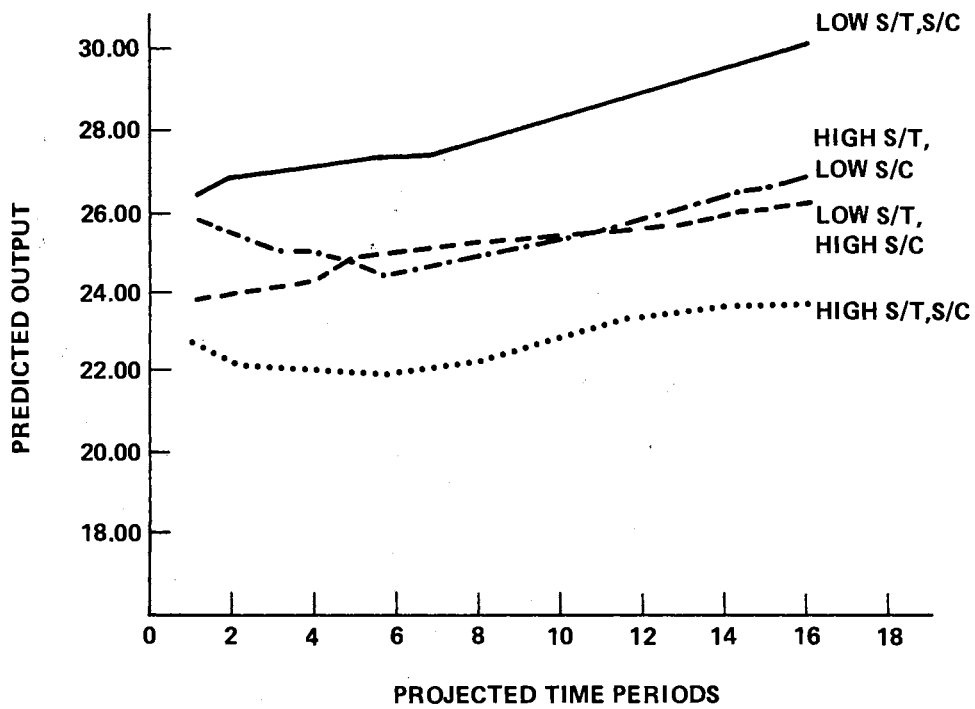


Figure 12. Laboratory B Predicted Output, Option Two, Case I.

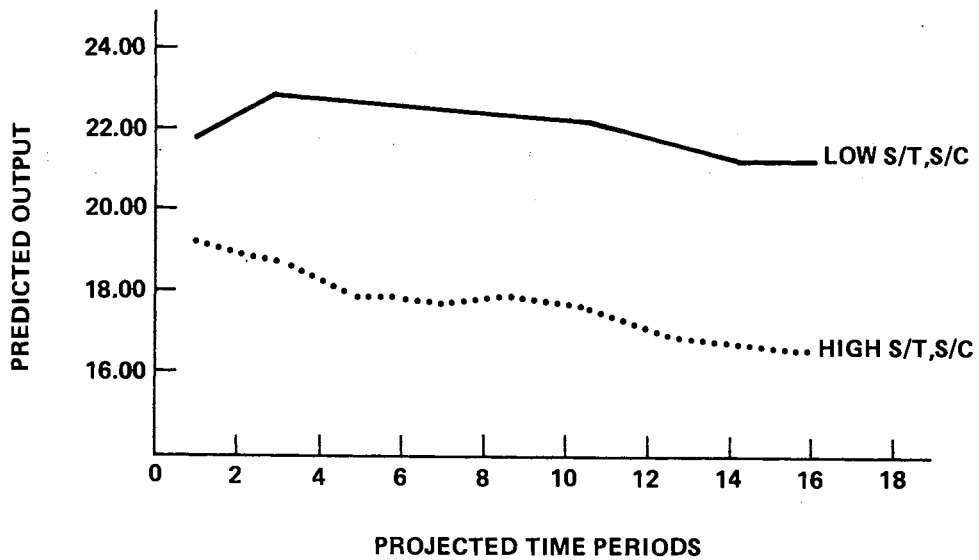


Figure 13. Laboratory B Predicted Output, Option Two, Case II.

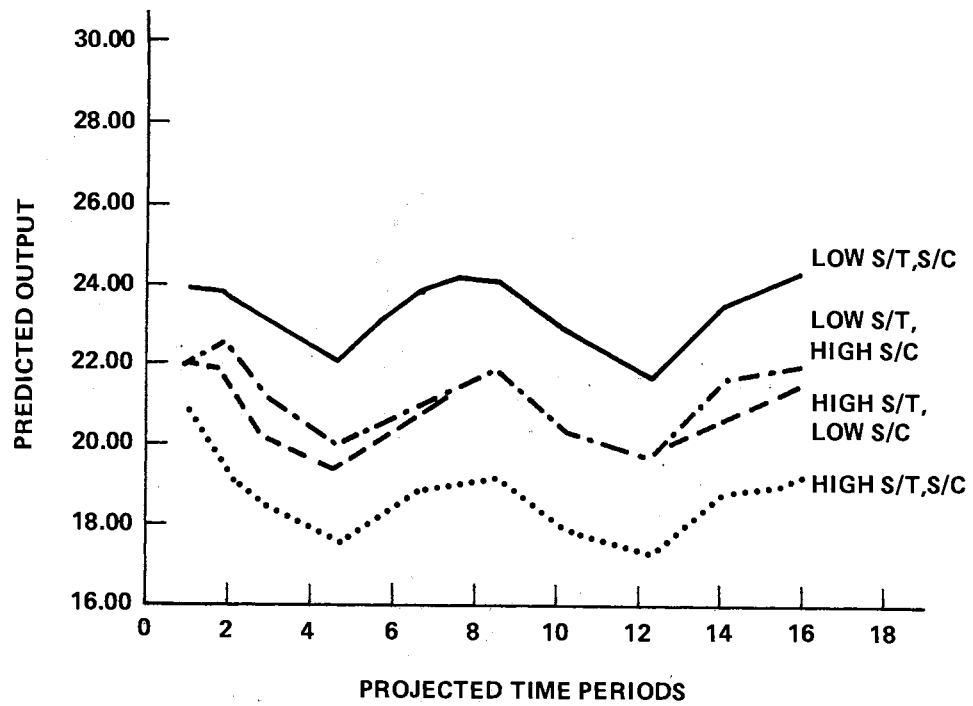


Figure 14. Laboratory B Predicted Output, Option Two, Case III.

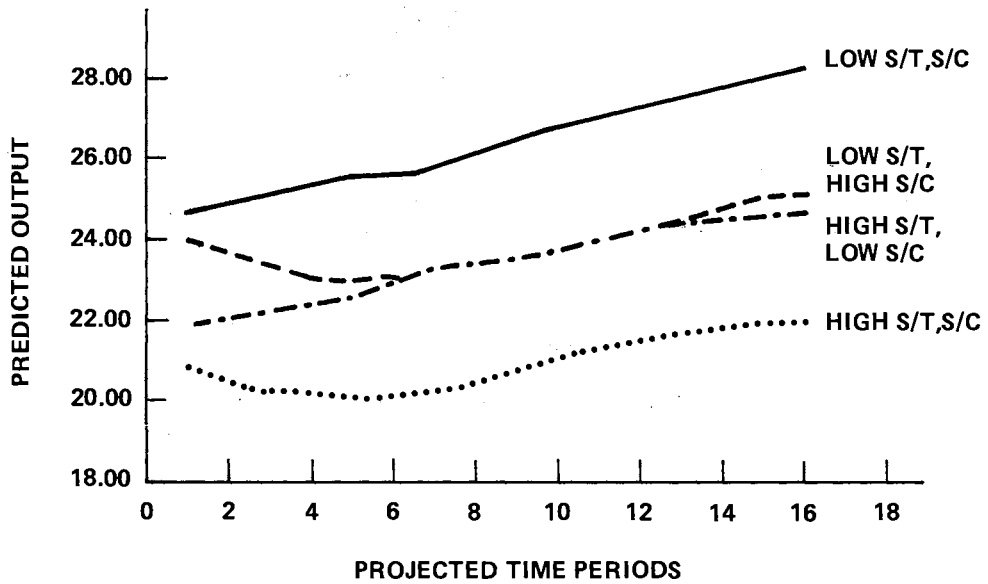


Figure 15. Laboratory B Predicted Output, Option Four, Case I.

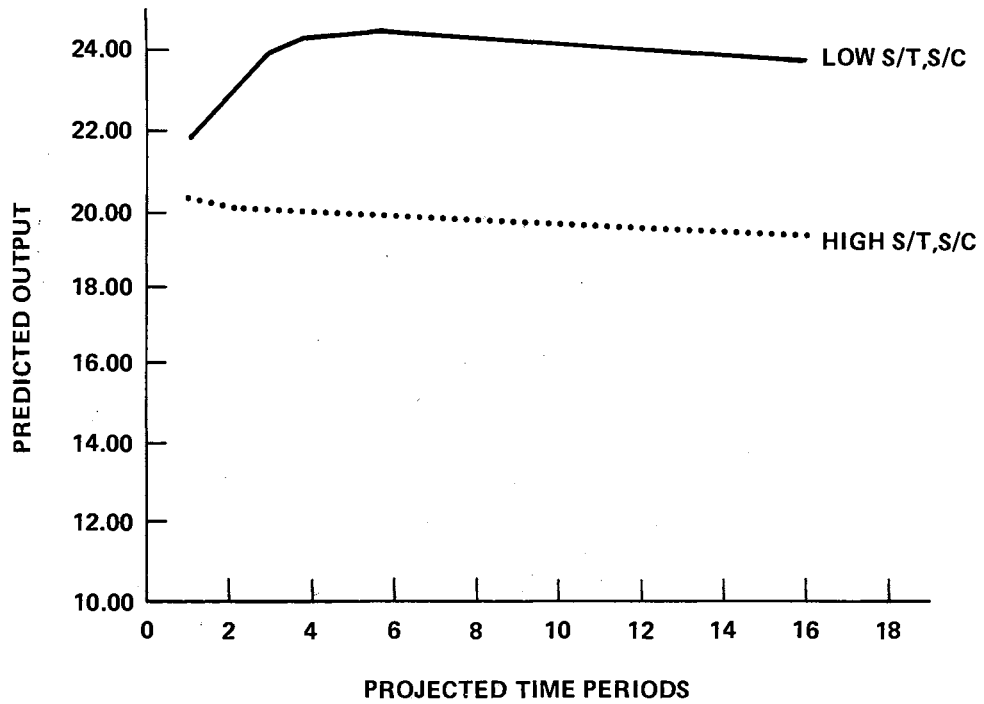


Figure 16. Laboratory B Predicted Output,
Option Four, Case II.

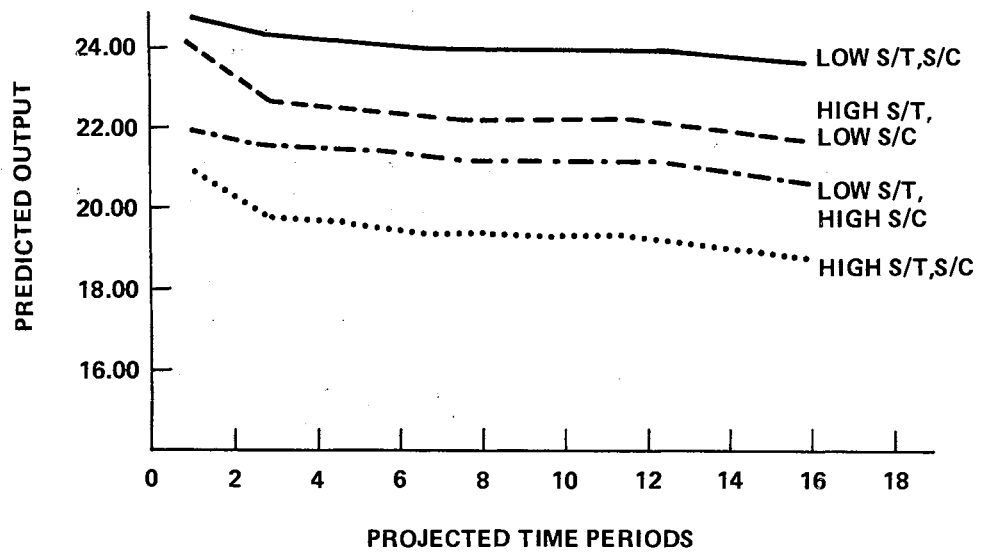


Figure 17. Laboratory B Predicted Output,
Option Four, Case III.

about equally sensitive to changes in the S/T and S/C ratios. This was indicated by their regression coefficients.

Case IV

In this case, the actual budgets were used as input data, together with average values of the ratios S/T and S/C. (These average values were obtained from Table VII.) Since the budget data used were actual values, the inflation factor was set to zero and program STAFF was then run. The projected output for laboratories A and B are shown in Figures 18 and 19. Only two options are shown in each figure, for the sake of clarity, since the remaining two options were near the two values depicted. The tabulated budget data together with the projected staffing levels are shown for both laboratories by Tables XXIII through XXXII. As can be seen from these tables and figures, option three provided a close approximation to the actual for laboratory A, whereas for laboratory B, option one provided a better approximation. It is felt that a closer approximation could have been obtained, if the capability for updating the S/T and S/C ratios had been incorporated into program STAFF. As it was, the results for this case confirm that the de facto staffing policy for both laboratories has been one of proportional increase or decrease (which is the policy followed by both options one and three). This case, in a sense, was therefore a validation of program STAFF for use in adjusting research organization staffing levels.

Comparison of the projected effective cost of the report for both laboratories disclosed the data in Table XXII; i. e., option four, if followed

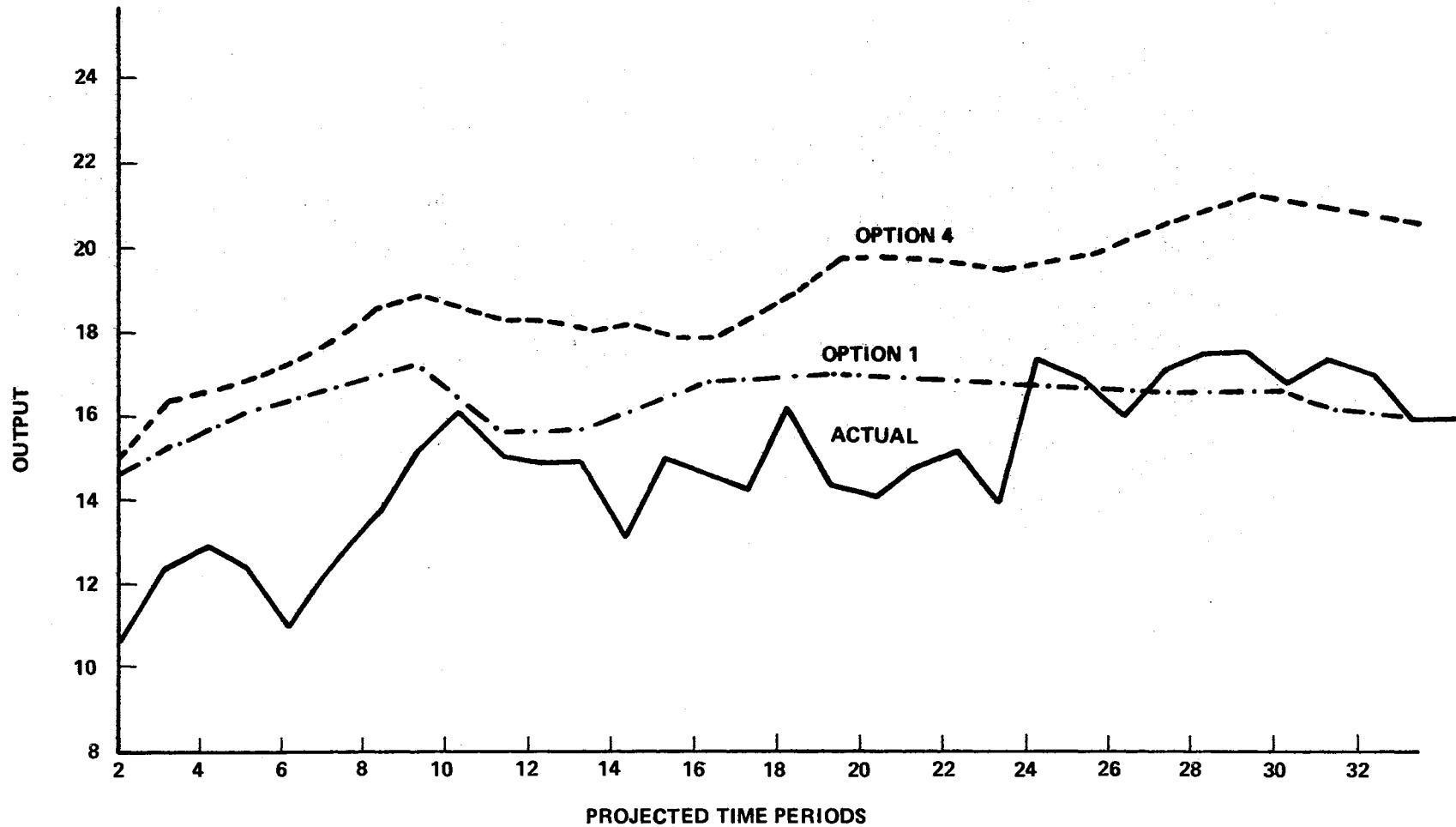


Figure 18. Actual and Predicted Output, Laboratory A, Case IV.

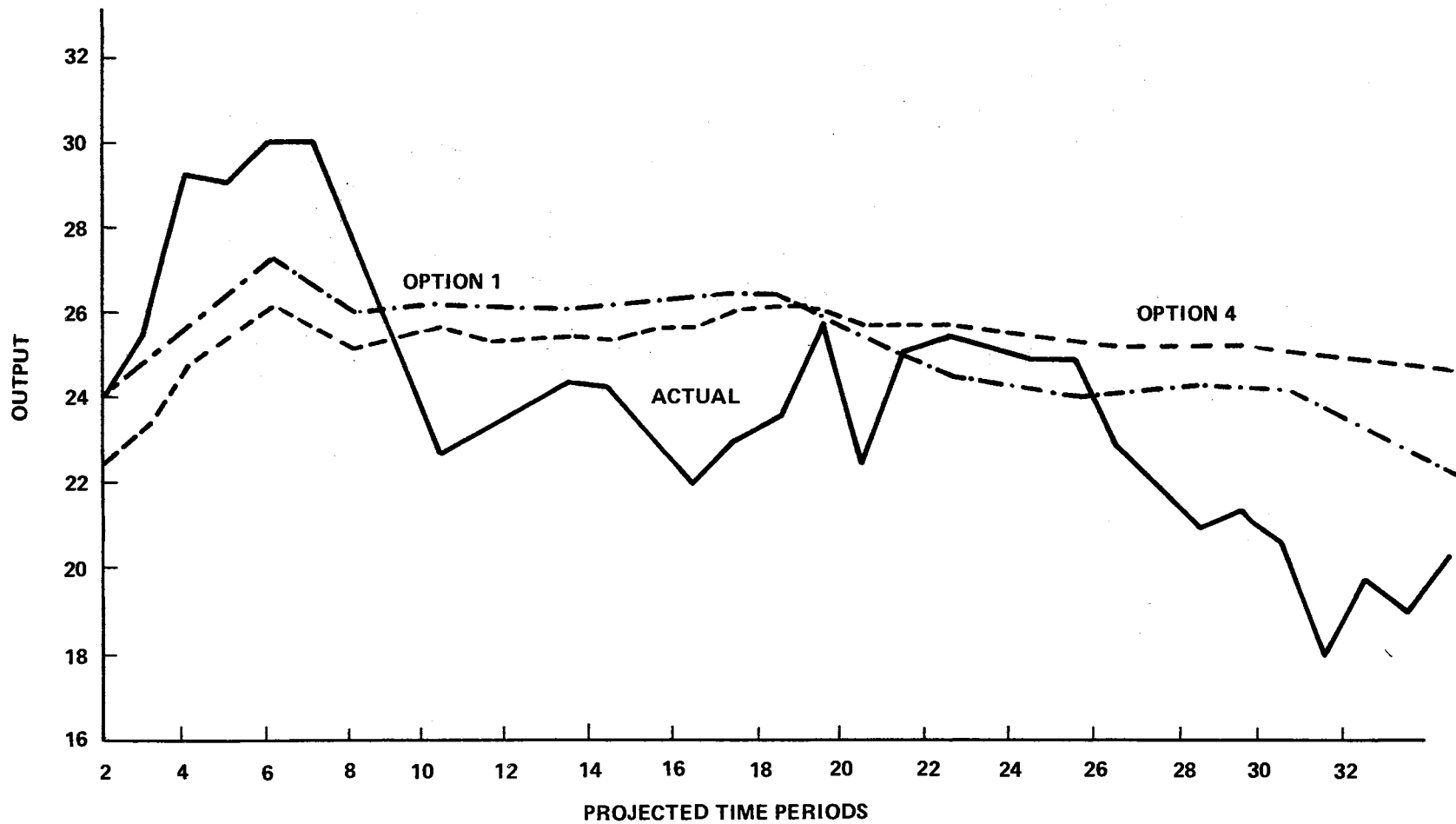


Figure 19. Actual and Predicted Output, Laboratory B, Case IV.

TABLE XXIII
COMPARISON OF REQUIRED AND PROJECTED
LABOR BUDGETS FOR CASE IV,
OPTION ONE, LABORATORY A

FISCAL YEAR	REQUIRED BUDGET (\$X1000)	PROJECTED BUDGET (\$X1000)	PER CENT CHANGE
1	837.	958.	14.
2	952.	1208.	26.
3	1187.	1529.	28.
4	1503.	1406.	-6.
5	1411.	1560.	10.
6	1543.	1757.	13.
7	1705.	1901.	11.
8	1879.	2044.	8.
9	2041.	2095.	2.

TABLE XXIV
 PROJECTED PERSONNEL STRENGTHS,
 LABORATORY A, OPTION ONE,
 CASE IV

QTR	T	C	B	S	TOTAL
1	9	8	3	44	64
2	9	8	3	44	64
3	9	8	3	44	64
4	9	8	3	44	64
5	11	10	4	55	80
6	11	10	4	55	80
7	11	10	4	55	80
8	11	10	4	55	80
9	14	12	5	70	101
10	14	12	5	70	101
11	14	12	5	70	101
12	14	12	5	70	101
13	13	11	6	65	95
14	13	11	6	65	95
15	13	11	6	65	95
16	13	11	6	65	95
17	14	12	7	71	104
18	14	12	7	71	104
19	14	12	7	71	104
20	14	12	7	71	104
21	15	13	8	80	116
22	15	13	8	80	116
23	15	13	8	80	116
24	15	13	8	80	116
25	16	14	7	89	126
26	16	14	7	89	126
27	16	14	7	89	126
28	16	14	7	89	126
29	17	15	7	96	135
30	17	15	7	96	135
31	17	15	7	96	135
32	17	15	7	96	135
33	17	15	9	98	139
34	17	15	9	98	139
35	17	15	9	98	139
36	17	15	9	98	139

TABLE XXV
 PROJECTED PERSONNEL STRENGTHS,
 LABORATORY A, OPTION TWO,
 CASE IV

QTR	T	C	B	S	TOTAL
1	9	9	3	45	62
2	9	9	3	45	62
3	9	9	3	45	62
4	9	9	3	45	62
5	11	11	4	57	79
6	11	11	4	57	79
7	11	11	4	57	79
8	11	11	4	57	79
9	14	14	5	72	99
10	14	14	5	72	99
11	14	14	5	72	99
12	14	14	5	72	99
13	12	12	6	65	97
14	12	12	6	65	97
15	12	12	6	65	97
16	12	12	6	65	97
17	14	14	7	73	101
18	14	14	7	73	101
19	14	14	7	73	101
20	14	14	7	73	101
21	15	16	8	82	113
22	15	16	8	82	113
23	15	16	8	82	113
24	15	16	8	82	113
25	17	17	7	89	122
26	17	17	7	89	122
27	17	17	7	89	122
28	17	17	7	89	122
29	18	19	7	96	132
30	18	19	7	96	132
31	18	19	7	96	132
32	18	19	7	96	132
33	18	19	9	96	142
34	18	19	9	96	142
35	18	19	9	96	142
36	18	19	9	96	142

TABLE XXVI
 PROJECTED PERSONNEL STRENGTHS,
 LABORATORY A, OPTION THREE,
 CASE IV

QTR	T	C	B	S	TOTAL
1	9	8	3	44	64
2	9	8	3	44	64
3	9	8	3	44	64
4	9	8	3	44	64
5	11	10	4	55	80
6	11	10	4	55	80
7	11	10	4	55	80
8	11	10	4	55	80
9	14	12	5	70	101
10	14	12	5	70	101
11	14	12	5	70	101
12	14	12	5	70	101
13	14	12	5	70	101
14	14	12	5	70	101
15	14	12	6	70	101
16	13	11	6	69	99
17	13	11	7	72	103
18	13	11	7	72	103
19	13	11	7	72	103
20	13	11	7	72	103
21	14	12	8	81	115
22	14	12	8	81	115
23	14	12	8	81	115
24	14	12	8	81	115
25	15	13	7	90	125
26	15	13	7	90	125
27	15	13	7	90	125
28	15	13	7	90	125
29	16	14	7	97	134
30	16	14	7	97	134
31	16	14	7	97	134
32	16	14	7	97	134
33	16	14	9	99	138
34	16	14	9	99	138
35	16	14	9	99	138
36	16	14	9	99	138

TABLE XXVII
 PROJECTED PERSONNEL STRENGTHS,
 LABORATORY A, OPTION FOUR,
 CASE IV

QTR	T	C	B	S	TOTAL
1	9	9	3	45	62
2	9	9	3	45	62
3	9	9	3	45	62
4	9	9	3	45	62
5	11	11	4	57	79
6	11	11	4	57	79
7	11	11	4	57	79
8	11	11	4	57	79
9	14	14	5	72	99
10	14	14	5	72	99
11	14	14	5	72	99
12	14	14	5	72	99
13	14	14	6	72	100
14	14	14	6	72	100
15	14	14	6	72	100
16	13	13	6	70	102
17	14	14	7	72	107
18	14	14	7	72	99
19	14	14	7	72	99
20	14	14	7	72	99
21	15	16	8	82	113
22	15	16	8	82	113
23	15	16	8	82	113
24	15	16	8	82	113
25	17	17	7	89	122
26	17	17	7	89	122
27	17	17	7	89	122
28	17	17	7	89	122
29	18	19	7	96	132
30	18	19	7	96	132
31	18	19	7	96	132
32	18	19	7	96	132
33	18	19	9	96	134
34	18	19	9	96	134
35	18	19	9	96	134
36	18	19	9	96	134

TABLE XXVIII
 COMPARISON OF REQUIRED AND PROJECTED
 LABOR BUDGETS FOR CASE IV,
 OPTION ONE, LABORATORY B

FISCAL YEAR	REQUIRED BUDGET (\$X1000)	PROJECTED BUDGET (\$X1000)	PER CENT CHANGE
1	3013.	3889.	29.
2	3880.	5393.	38.
3	5383.	5845.	8.
4	5834.	6052.	3.
5	6032.	6400.	6.
6	6374.	6002.	-5.
7	5999.	5759.	-4.
8	5750.	5765.	0.
9	5773.	5377	-8.

TABLE XXIX
 PROJECTED PERSONNEL STRENGTHS,
 LABORATORY B, OPTION ONE,
 CASE IV

QTR	T	C	B	S	TOTAL
1	29	36	2	190	257
2	29	36	2	190	257
3	29	36	2	190	257
4	29	36	2	190	257
5	40	50	4	264	358
6	40	50	4	264	358
7	40	50	4	264	358
8	40	50	4	264	358
9	43	54	5	286	388
10	43	54	5	286	388
11	43	54	5	286	388
12	43	54	5	286	388
13	44	56	6	296	402
14	44	56	6	296	402
15	44	56	6	296	402
16	44	56	6	296	402
17	46	59	6	314	425
18	46	59	6	314	425
19	46	59	6	314	425
20	46	59	6	314	425
21	43	55	5	295	398
22	43	55	5	295	398
23	43	55	5	295	398
24	43	55	5	295	398
25	41	52	6	283	382
26	41	52	6	283	382
27	41	52	6	283	382
28	41	52	6	283	382
29	41	52	6	283	382
30	41	52	6	283	382
31	41	52	6	283	382
32	41	52	6	283	382
33	37	47	8	258	350
34	37	47	8	258	350
35	37	47	8	258	350
36	37	47	8	258	350

TABLE XXX
 PROJECTED PERSONNEL STRENGTHS,
 LABORATORY B, OPTION TWO
 CASE IV

QTR	T	C	B	S	TOTAL
1	32	32	2	194	260
2	32	32	2	194	260
3	32	32	2	194	260
4	32	32	2	194	260
5	44	45	4	268	361
6	44	45	4	268	361
7	44	45	4	268	361
8	44	45	4	268	361
9	48	48	5	288	389
10	48	48	5	288	389
11	48	48	5	288	389
12	48	48	5	288	389
13	49	49	6	298	402
14	49	49	6	298	402
15	49	49	6	298	402
16	49	49	6	298	402
17	52	52	6	315	415
18	52	52	6	315	415
19	52	52	6	315	415
20	52	52	6	315	415
21	48	48	5	295	396
22	48	48	5	295	396
23	48	48	5	295	396
24	48	48	5	295	396
25	46	46	6	282	380
26	46	46	6	282	380
27	46	46	6	282	380
28	46	46	6	282	380
29	46	46	6	282	380
30	46	46	6	282	380
31	46	46	6	282	380
32	46	46	6	282	380
33	42	42	8	257	349
34	42	42	8	257	349
35	42	42	8	257	349
36	42	42	8	257	349

TABLE XX XI
 PROJECTED PERSONNEL STRENGTHS,
 LABORATORY B, OPTION THREE,
 CASE IV

QTR	T	C	B	S	TOTAL
1	29	36	2	190	257
2	29	36	2	190	257
3	29	36	2	190	257
4	29	36	2	190	257
5	40	50	4	264	358
6	40	50	4	264	358
7	40	50	4	264	358
8	40	50	4	264	358
9	43	54	5	286	388
10	43	54	5	286	388
11	43	54	5	286	388
12	43	54	5	286	388
13	44	56	6	296	402
14	44	56	6	296	402
15	44	56	6	296	402
16	44	56	6	296	402
17	46	59	6	314	425
18	46	59	6	314	425
19	46	59	6	314	425
20	46	59	6	314	425
21	46	59	5	314	424
22	46	59	5	314	424
23	46	59	5	314	424
24	45	58	5	310	418
25	45	58	6	310	419
26	45	58	6	310	419
27	45	58	6	310	419
28	44	57	6	306	413
29	44	57	6	306	413
30	44	57	6	306	413
31	44	57	6	306	413
32	43	56	6	302	407
33	43	56	8	302	409
34	43	56	8	302	409
35	43	56	8	302	409
36	43	56	8	302	409

TABLE XXXI I
 PROJECTED PERSONNEL STRENGTHS,
 LABORATORY B, OPTION FOUR,
 CASE IV

QTR	T	C	B	S	TOTAL
1	32	32	2	194	260
2	32	32	2	194	260
3	32	32	2	194	260
4	32	32	2	194	260
5	44	45	4	268	361
6	44	45	4	268	361
7	44	45	4	268	361
8	44	45	4	268	361
9	48	48	5	288	389
10	48	48	5	288	389
11	48	48	5	288	389
12	48	48	5	288	389
13	49	49	6	298	402
14	49	49	6	298	402
15	49	49	6	298	402
16	49	49	6	298	402
17	52	52	6	315	425
18	52	52	6	315	425
19	52	52	6	315	425
20	52	52	6	315	425
21	52	52	5	315	424
22	52	52	5	315	424
23	52	52	5	315	424
24	51	51	5	310	417
25	51	51	6	310	418
26	51	51	6	310	418
27	51	51	6	310	418
28	50	50	6	305	411
29	50	50	6	305	411
30	50	50	6	305	411
31	50	50	6	305	411
32	49	49	6	300	404
33	49	49	8	299	405
34	49	49	8	299	405
35	49	49	8	299	405
36	48	48	8	295	399

as a policy, would have yielded a more cost-effective utilization of labor funds. This policy would have resulted in higher report output (or conversely, fewer personnel for the same number of reports). These results have been depicted in Figures 20 and 21 for Laboratories A and B, respectively.

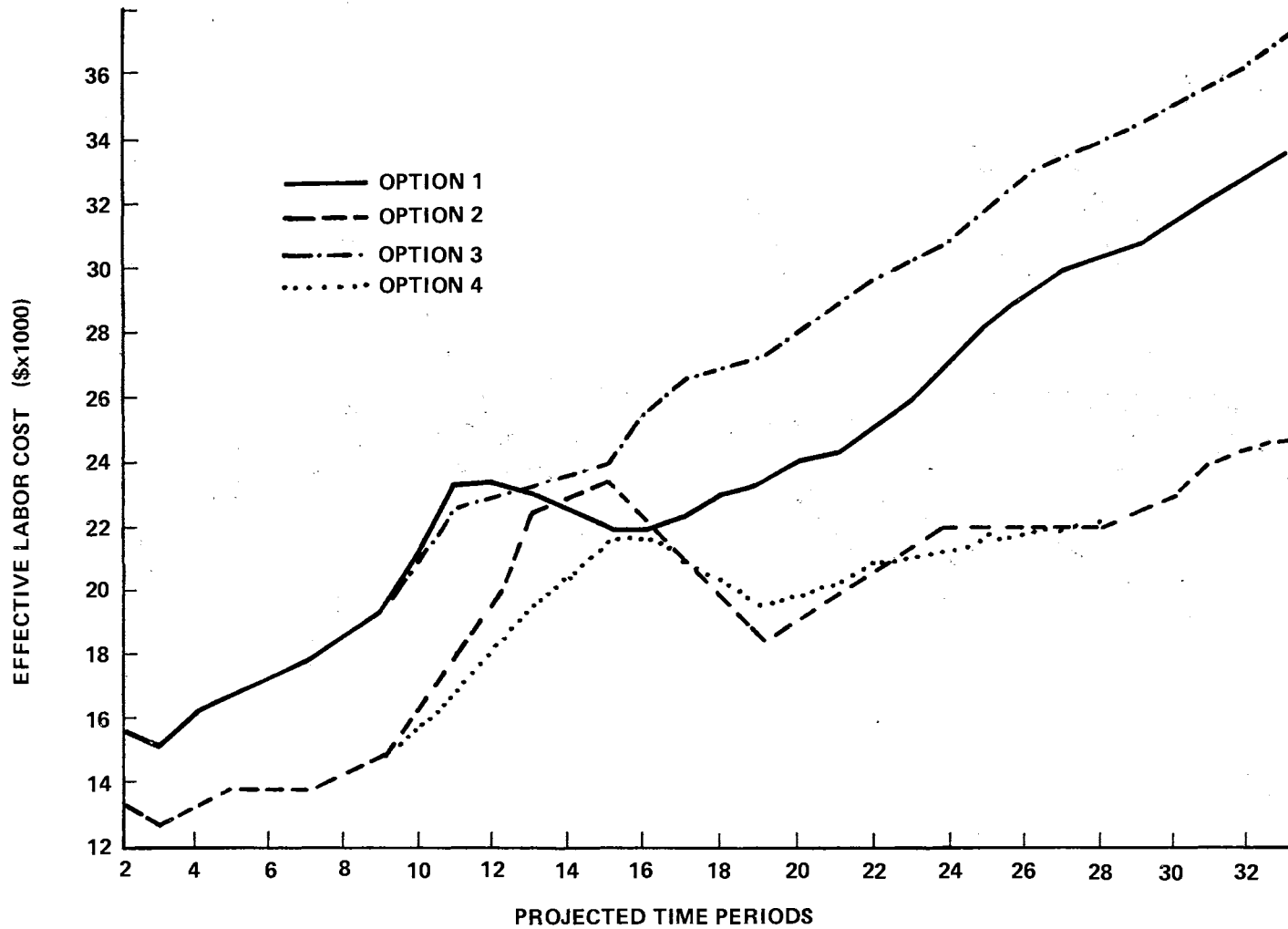


Figure 20. Effective Labor Cost per Report, Laboratory A, Case IV.

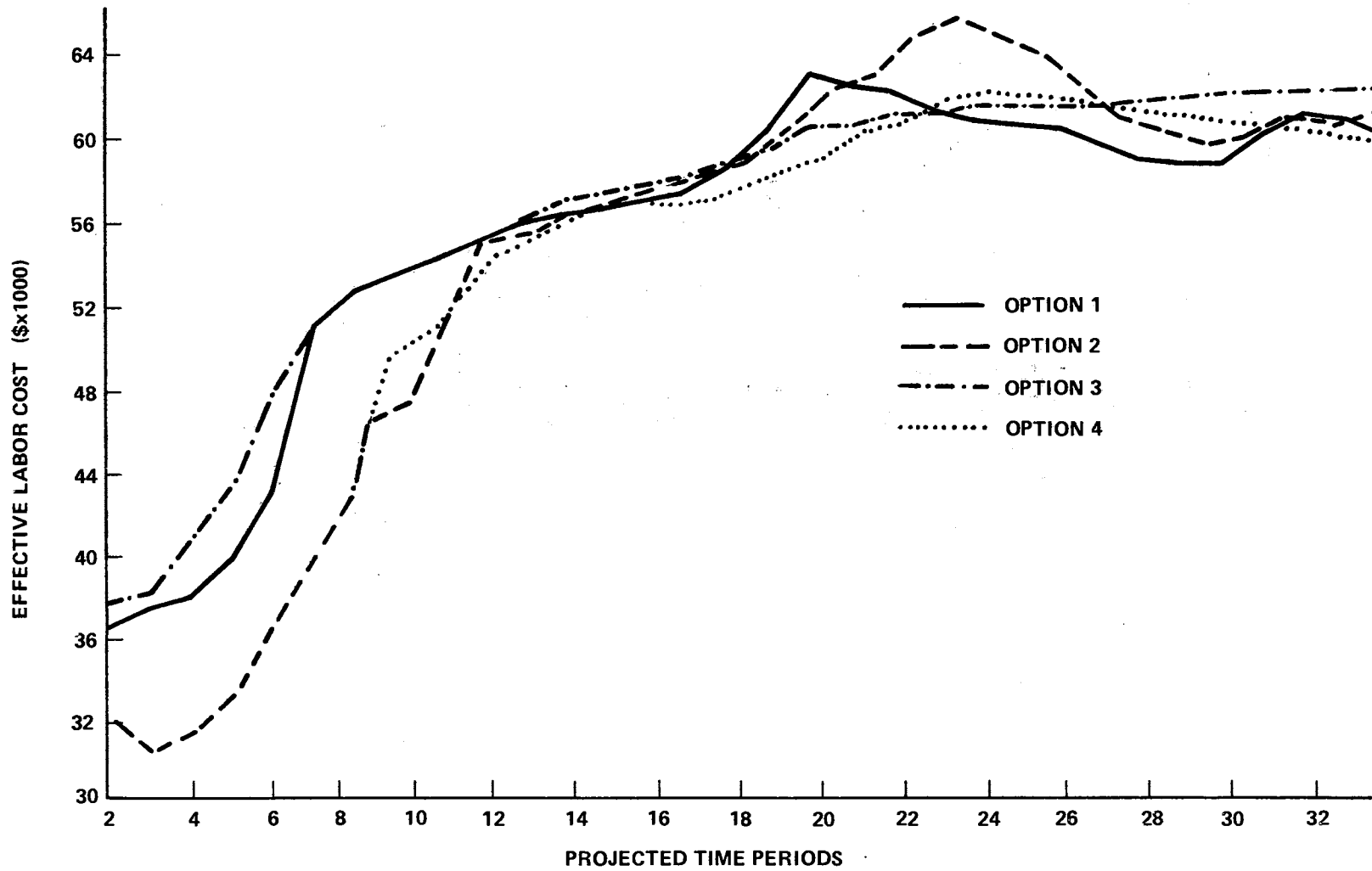


Figure 21. Effective Labor Cost per Report, Laboratory B, Case IV.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Summary and Conclusions

As discussed in Chapter I, available evidence and theory suggested that research publications could be used as an output measure of the research organization. This study undertook to show that output (in the form of publications) could be predicted by the input to the selected research organizations (in the form of skill categories). In addition, the study has the second objective of applying the obtained prediction (regression) function in computer program STAFF, which permitted a rapid assessment of various staffing options under various conditions.

These objectives were achieved as described in Chapters III and IV. The obtained regression expression indicated that while predicted output depends on the total number of personnel in the research organization, this output is equally dependent upon the ratios S/T and S/C . As illustrated by Figure 9, unfavorable ratios during a growth period can negate any apparent benefit of increased staff levels, as far as output may be concerned.

While the use of moving averages and time lags at first seemed to be a complication, little difficulty was created by them in manipulating the data and

interpreting the results of the data analyses. Neither was any difficulty encountered in using them in program STAFF.

Because the obtained regression function contained the ratios S/T and S/C, the best staffing options generally were those which maintained or improved these ratios. However, there were conditions encountered which indicated that this was not always true (Tables XX, XXI, and XXII). This bespeaks the need for a complete evaluation of the various alternatives under the various anticipated conditions, rather than simply following a "rule of thumb," such as always taking the option which indicate the best ratios of S/T and S/C.

Program STAFF, however, is not limited to use with the particular regression function obtained. Other functions can be used, if desired, or none at all. Two important features of STAFF cannot be used if the latter approach is taken. These are the projected output, with confidence limits, and the computation of an effective cost per report. However, the projected staffing, according to several options available to the research manager, can still be obtained. Program STAFF was written with the desire to have considerable versatility inherent in it. Additional staffing options can be included with little modification to the basic program. While the basic logic was established for the particular set of variables of interest in this study, it is adaptable to other ratios and variables. It is believed that the utility of STAFF has been satisfactorily demonstrated. It can quickly provide the research manager with projections for the various combinations of factors and events.

Similarly, program REGR, by modification to its input subroutine DATA, can be used to search for other forms of the regression function. This should be of interest to the potential users in other research environments, since no claim is made as to the general applicability of the function obtained in this study. Indeed, no assurance exists that the obtained function will continue to be valid as an output predictor. More data from more research organizations are required before it can be assured that the obtained regression expression generally holds. Although available evidence suggests a logarithmic function for the input-output relationship, such a function as obtained by regression analysis is only an approximation. As more data are analyzed, of course, better approximations hopefully will be obtained. Thus, while the obtained relation was suitable for this study, it is believed that future investigations should attempt to find other possible relations, at least until it can be generally stated that an expression of the form obtained holds for other research organizations. Even if the form remains the same, it would not be unexpected if the values of the coefficients changed.

It is not surprising that the regression function is complex, because the research organization as described herein is a complex organization in the sense described by Barnard (2). The simple or unit organization appears to be the research team composed of S, T, and C skill categories. Although this study did not concern itself with the characteristics of the unit organization, it is possible that the presence and character of the double logarithm of N (the total personnel strength of the laboratory) reflect the dependence of output to the number of functioning research teams rather than raw totals of

personnel. This point of view is supported by the presence of the S/T and S/C ratios in the regression function. Thus, output is apparently not increased by the addition of scientists alone, because this tends to degrade these ratios and hence reduce total output. In terms of organizational behavior, this suggests that a researcher without an adequate supporting technician and clerical assistance not only may not be productive himself, but his presence may adversely affect his fellow researchers. Presuming that the research personnel maintain a given level of interaction among themselves, the addition of an individual represents a decrease in productive time available if this presumed level of interaction is maintained.

The reverse argument holds for a decrease in research personnel. In the case of changes in the T and C categories, it appears that if only numbers of reports are important, then these categories should be increased continuously to improve the S/T and S/C ratios. Accepting the existence of a research unit composed of S, T, and C personnel and postulating that the staffing of this unit is and has been nonoptimum, by virtue of resource limitations, then it is to be expected that there is some limit on the amount of increase of T and C. Hopefully, future studies may determine what this limit is. However, the existence of such a limit can at this time only be postulated. Reduction of T and C, without some reduction in S would, of course, create the above described situation of inadequately supported researchers, as represented by unsuitable S/T and S/C ratios.

Before generalizing upon the significance of this study for the research manager, a comment upon the nature of the research organization is in order.

It must be remembered that the research organization's basic mission is to advance knowledge. Thus, in the particular fields of interest, it is to be expected that as research progresses and the state-of-knowledge is furthered; then, over a period of time there should be a decrease in research publications pertaining to the fields of study. That is, as more is learned, the effort to extend the state-of-knowledge either must be increased or there is less new knowledge to be learned. The foregoing would be the case if old research areas were not abandoned and new ones attacked by the research organization. It appears that such a renewal process is indeed occurring in the research organization, because this type of organization, just like any other and as described by Barnard (2), must show evidence of meeting its objectives or be disbanded. Thus, for a given man-level effort, research output, in the form of publications, can be expected to be more or less constant and proportional to the level of effort. This, of course, has been substantiated by this study and should hold true for any mission-oriented research organization.

It is therefore possible that this can provide a means for informing the research manager whether he has been deleting older, less profitable research projects in a timely manner. In other words, if report output appears to be dropping for no other assignable reason (such as delays in facilities or equipment, or because key personnel have been diverted to other duties), then this may be taken as evidence that old projects are not being replaced by newer ones often enough. It should be noted that labor costs can be expected to rise more or less constantly because of inflation and longevity costs.

Hence, the research manager should be warned by increases in his "cost per report" above the expected level if there are no other assignable reasons.

It should be recognized by the research manager that low ratios of S/T and S/C are desirable if report output is to be maintained. The addition of research personnel must be accomplished by a proportional increase in the T and C personnel categories. It is worth noting that the S/C and S/T ratios appear to be approximately equal in this study. Thus, it appears that while T personnel are necessary for performing those tasks leading to publication of reports, the C personnel are just as important for turning laboratory and manuscripts into the final output. Since clerical personnel are generally easier to replace than skilled or semiskilled technicians, it appears that the research manager should approach his hire-and-fire decision with this in mind.

Finally, it is noted that a finite number of skills required in the research organization exists, particularly in regard to the technician category. Hence, the research manager cannot increase this category at will to improve the S/T ratio. Too small a ratio - on the order of S/T equal to a value of two to four - may represent underutilization of personnel in this category. It is conjectured then that an optimum ratio should be in the range of four to six. The same argument can be made for clerical help as well. In other words, as long as the S/T and S/C ratios are between four and six, a near-optimum mix should be realized. Ratios lower than this would indicate underutilization of T and C personnel; higher ratios would indicate improper utilization of S personnel and possibly overworking of the T and C categories.

Recommendations for Further Study

This study concerned itself with only four categories of labor:

(1) technician, (2) clerical, (3) business/professional, and (4) scientific/engineering. Of these, at least two, the technician and scientific/engineering categories, can be further broken down by discipline. Future studies could investigate further breakdown. For example, the physical sciences and the engineering disciplines could require extension of the regression model to include additional ratios of these to the other categories, as well as to each other. In addition, the size, composition, and behavior of the research unit as a functioning entity should be investigated, and, if appropriate, the regression model modified to reflect the results of such investigations.

This study was restricted to two unique laboratories during a discrete time period. The apparent input-output relationships of other types of research organizations should be investigated. Whether there is a generalized input-output expression or whether each type of research organization may have its own peculiar expression should be determined. It is to be expected that as newer and more diverse data are obtained that the input-output coefficients may take a different form than was obtained by this study. The approach of future studies should be similar to that used during this study.

It is recommended that care be exercised in applying the results of such future studies. The researcher is a creative person; he cannot be treated in the same fashion as an ordinary laborer or skilled technician. While output, in the form of reports, may be increased by varying personnel levels and

mixes, nothing in this study warrants the presumption that the rate of publication can be increased on an individual basis.

Finally, it would be desirable if program STAFF was used, under controlled conditions, in actual situations. This could be done to a limited extent by using it to project the anticipated results of managerial staffing decisions and then comparing these results to what actually transpired. This should not be particularly costly. Assuming that a quarterly breakdown of data would continue to be available, another two or three year's data should be sufficient to confirm the utility of the program. Failing this, such data should then help indicate to what extent STAFF can be modified or improved to be of continuing benefit to the research manager.

Finally, it is stressed that the use of REGR and STAFF was not intended to replace the experience and judgement of the research manager. Rather, the overall purpose of the study was to provide the research manager with an added management tool tailored to his needs. Within the limits of the scope of this study and the environment under study, it is believed that this purpose has been achieved.

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APPENDIX A

SURVEY QUESTIONNAIRE AND
LETTER OF TRANSMITTAL

SURVEY QUESTIONS

1. The majority of technical reports published by center personnel are Internal Notes (IN's) and Technical Memoranda (TM's). Employees A and B are both equally qualified to share in a bonus of \$ 100.00, except that A has published one Internal Note in the past six months, whereas B has published one Technical Memorandum in the same period. How would you divide the \$ 100.00 between A and B?

A: _____

B: _____
2. Which of the following best describe your present position?
 - a. Senior Scientist _____
 - b. Junior Scientist _____
 - c. Staff Scientist _____
 - d. Project Engineer _____
 - e. Engineer _____
 - f. Branch Chief or higher position _____
3. Please provide the following personal data:
 - a. Age _____
 - b. Degrees _____
 - c. GS Rating _____
 - d. Years at MSFC _____

A& TS-MA-T

TO: Distribution

FROM: A& TS-MA-T/Chief, Training Branch

SUBJECT: Survey on Scientific/Technical Publications

The attached questionnaire is part of the thesis preparation work of one of our Center employees. We would appreciate your cooperation in responding to this survey as quickly as possible.

These forms are being sent to a sample of engineering/scientific personnel. The data obtained will be used primarily by the thesis writer; however, the statistics, analyses, conclusions and recommendations will be available to interested center personnel for use in planning and management.

This survey is a part of our continuing support to personnel engaged in job-related study applied toward an advanced degree. The answers, of course, are anonymous.

Thank you for your cooperation and prompt response.

James F. Dowdy

1 Enclosure: a/s

APPENDIX B

PROGRAM REGR AND SUBROUTINES

```

*NAME REGR
*ONE WORD INTEGERS
*IOCS(CARD,1132PRINTER)
  DIMENSION TITLE(60),XBAR(10),STD(10),D(10),RY(10)
  DIMENSION ISAVE(10),B(10),SB(10),T(10),RX(100),R(60)
  DIMENSION ANS(10)
  COMMON MX,MY
  MY=2
  MX=3
  1 FORMAT(I5,2I2,60A1)
  2 FORMAT(///,20X,60A1,/)
  3 FORMAT(//9H VARIABLE,5X,4HMEAN,6X,8HSTANDARD,6X,11HCO
  1RELATION,4X,10HREGRESSION,4X,10HSTD. ERROR,5X,8HCOMP
  2UTED/6H NO.,18X,9HDEVIATION,7X,6HX VS Y,7X,11HCOEFF
  4ICIENT,3X,12HOF REG.COEF.,3X,7HT VALUE)
  4 FORMAT(/,I4,6F14.5)
  5 FORMAT(//,10H DEPENDENT)
  6 FORMAT(///, 2X,'INTERCEPT = ',F 8.5, 2X,'MULTIPLE
  2CORRELATION = ',F8.5,2X,'STD. ERROR OF ESTIMATE = ',
  3F8.5,/)
  7 FORMAT(//,21X,39HANALYSIS OF VARIANCE FOR THE REGRES
  1SION//5X,19HSOURCE OF VARIATION,7X,7HDEGREES,7X,'SUM
  2OF',10X,'MEAN',13X,'F VALUE/30X,'OF FREEDOM',4X,'SQUA
  4RES)
  8 FORMAT(/30H ATTRIBUTABLE TO REGRESSION ,I6,3F16.5/
  130' DEVIATION FROM REGRESSION ,I6,2F16.5)
  9 FORMAT(/5X,5HTOTAL,19X,I6,F16.5)
  10 FORMAT(36I2)
  16 FORMAT(1H1)
  45 FORMAT(///,8X,'T',10X,'C',9X,' P ',9X,'S',10X,'P',
  19X,'S/T',8X,'S/C',8X,'LN N',/)
  50 FORMAT(/////////)
100 READ(2,1)N,M,NS,TITLE
  IO=0
  WRITE(MX,16)
  WRITE(MX,50)
  WRITE(MX,45)
  CALL CORRE(N,M,IO,X,XBAR,STD,RX,R,D,B,T)
  IF(NS)108,108,109
  GO TO 300
109 WRITE(MX,16)
  DO 200 I=1,NS
  WRITE(MX,2) TITLE
  READ(MY,10)NRESI,NDEP,K,(ISAVE(J),J=1,K)
  CALL ORDER(N,R,NDEP,K,ISAVE,RX,RY)
  CALL MINV(RX,K,DET,B,T)
  IF(DET)112,110,112
  GO TO 200
112 CALL MULTR (N,K,XBAR,STD,D,RX,RY,ISAVE,B,SB,T,ANS)
  MM=K+1
  WRITE(MX,3)
  DO 115 J=1,K
  L=ISAVE(J)

```

```

115 WRITE(MX,4)L,XBAR(L),STD(L),RY(J),B(J),SB(J),T(J)
    WRITE(MX,5)
    L=ISAVE(MM)
    WRITE(MX,4)L,XBAR(L),STD(L)
    WRITE(MX,6)ANS(1),ANS(2),ANS(3)
    WRITE(MX,16)
    WRITE(MX,50)
    WRITE(MX,7)
    I=ANS(8)
    WRITE(MX,8)K,ANS(4),ANS(6),ANS(10),L,ANS(7),ANS(9)
    L=N-1
    SUM=ANS(4)+ANS(7)
    WRITE(MX,9)L,SUM
200 CONTINUE
    WRITE(MX,16)
    GO TO 100
300 STOP
    END

```

```

SUBROUTINE CORRE (N,M,IO,X,XBAR,STD,RX,R,B,D,T)
DIMENSION X(1),XBAR(1),STD(1),RX(1),R(1),B(1),D(1),T(1)
DO 100 J=1,M
    B(J)=0.0
100 T(J)=0.0
    K=(M*M+M)/2
    DO 102 I=1,K
102 R(I)=0.0
    FN=N
    L=0
    IF(IO) 105, 127, 105
105 DO 108 J=1,M
    DO 107 I=1,N
        L=L+1
107 T(J)=T(J)+X(L)
        XBAR(J)=T(J)
108 T(J)=T(J)/FN
    DO 115 I=1,N
        JK=0
        L=I-N
        DO 110 J=1,M
            L=L+N
            D(J)=X(L)-T(J)
110 R(J)=R(J)+D(J)
        DO 115 J=1,M
        DO 115 K=1,J
            JK=JK+1
115 R(JK)=R(JK)+D(J)*D(K)
        GO TO 205
127 IF(N-M)130,130,135
130 KK=N
    GO TO 137
135 KK=M

```



```

137 DO 140 I=1, KK
    CALL DATA (M, D)
    DO 140 J=1, M
        T(J)=T(J)+D(J)
        L=L+1
140 RX(L)=D(J)
    FKK=KK
    DO 150 J=1, M
        XBAR(J)=T(J)
150 T(J)=T(J)/FKK
    L=0
    DO 180 I=1, KK
        JK=0
        DO 170 J=1, M
            L=L+1
170 D(J)=RX(L)-T(J)
        DO 180 J=1, M
            B(J)=B(J)+D(J)
            DO 180 K=1, J
                JK=JK+1
180 R(JK)=R(JK)+D(J)*D(K)
        IF(N-KK) 205, 205, 185
185 KK=N-KK
    DO 200 I=1, KK
        JK=0
        CALL DATA (M, D)
        DO 190 J=1, M
            XBAR(J)=XBAR(J)+D(J)
            D(J)=D(J)-T(J)
190 B(J)=B(J)+D(J)
        DO 200 J=1, M
            DO 200 K=1, J
                JK=JK+1
200 R(JK)=R(JK)+D(J)*D(K)
205 JK=0
        DO 210 J=1, M
            XBAR(J)=XBAR(J)/FN
            DO 210 K=1, J
                JK=JK+1
210 R(JK)=R(JK)-B(J)*B(K)/FN
        JK=0
        DO 220 J=1, M
            JK=JK+J
220 STD(J)=SQRT(ABS(R(JK)))
        DO 230 J=1, M
            DO 230 K=J, M
                JK=J+(K*K-K)/2
                L=M*(J-1)+K
                RX(L)=R(JK)
                L=M*(K-1)+J
                RX(L)=R(JK)
                IF(STD(J)*STD(K)) 225, 222, 225
222 R(JK)=0.0

```

```

      GO TO 230
225  R(JK)=R(JK)/(STD(J)*STD(K))
230  CONTINUE
      FN=SQRT(FN-1.0)
      DO 240 J=1,M
240  STD(J)=STD(J)/FN
      L=-M
      DO 250 I=1,M
      L=L+M+1
250  R(I)=RX(L)
      RETURN
      END

```

```

      SUBROUTINE ORDER (M,R,NDEP,K,ISAVE,RX,RY)
      DIMENSION R(1),ISAVE(1),RX(1),RY(1)
      MM=0
      DO 130 J=1,K
      L2=ISAVE(J)
      IF(NDEP-L2) 122,123,123
122  L=NDEP+(L2*L2-L2)/2
      GO TO 125
123  L=L2+(NDEP*NDEP-NDEP)/2
125  RY(J)=R(L)
      DO 130 I=1,K
      L1=ISAVE(I)
      IF(L1-L2) 127,128,128
127  L=L1+(L2*L2-L2)/2
      GO TO 129
128  L=L2+(L1*L1-L1)/2
129  MM=MM+1
130  RX(MM)=R(L)
      ISAVE(K+1)=NDEP
      RETURN
      END

```

```

      SUBROUTINE MINV(A,N,D,L,M)
      DIMENSION A(1),L(1),M(1)
C      SEARCH FOR LARGEST ELEMENT
      D=1.0
      NK=-N
      DO 80 K=1,N
      NK=NK+N
      L(K)=K
      M(K)=K
      KK=NK+K
      BIGA=A(KK)
      DO 20 J=K,N
      IZ=N*(J-1)
      DO 20 I=K,N
      IJ=IZ+I

```

```
10 IF (ABS(BIGA)-ABS(A(IJ))) 15,20,20
15 BIGA=A(IJ)
   L(K)=I
   M(K)=J
20 CONTINUE
   J=L(K)
   IF(J-K) 35,35,25
25 KI=K-N
   DO 30 I=1,N
   KI=KI+N
   HOLD=-A(KI)
   JI=KI-K+J
   A(KI)=A(JI)
30 A(JI)=HOLD
35 I=M(K)
   IF(I-K) 45,45,38
38 JP=N*(I-1)
   DO 40 J=1,N
   JK=NK+J
   JI=JP+J
   HOLD=-A(JK)
   A(JK)=A(JI)
40 A(JI)=HOLD
45 IF (ABS(BIGA)-1.E-20) 46,46,48
46 D=0.0
   RETURN
48 DO 55 I=1,N
   IF(I-K) 50,55,50
50 IK=NK+I
   A(IK)=A(IK)/(-BIGA)
55 CONTINUE
   DO 65 I=1,N
   IK=NK+I
   HOLD=A(IK)
   IJ=I-N
   DO 65 J=1,N
   IJ=IJ+N
   IF(I-K) 60,65,60
60 IF(J-K) 62,65,62
62 KJ=IJ-I+K
   A(IJ)=HOLD*A(KJ)+A(IJ)
65 CONTINUE
   KJ=K-N
   DO 75 J=1,N
   KJ=KJ+N
   IF(J-K) 70,75,70
70 A(KJ)=A(KJ)/BIGA
75 CONTINUE
   D=D*BIGA
   A(KK)=1.0/BIGA
80 CONTINUE
   K=N
100 K=(K-1)
   IF(K) 150,150,105
```

```

105 I=L(K)
    IF(I-K) 120,120,108
108 JQ=N*(K-1)
    JR=N*(I-1)
    DO 110 J=1,N
        JK=JQ+J
        HOLD=A(JK)
        JI=JR+J
        A(JK)=-A(JI)
110 A(JI)=HOLD
120 J=M(K)
    IF(J-K) 100,100,125
125 KI=K-N
    DO 130 I=1,N
        KI=KI+N
        HOLD=A(KI)
        JI=KI-K+J
        A(KI)=-A(JI)
130 A(JI)=HOLD
    GO TO 100
150 RETURN
    END

```

```

SUBROUTINE MULTR (N,K,XBAR,STD,D,RX,RY,ISAVE,B,SB,T,ANS)
DIMENSION XBAR(1),STD(1),D(1),RX(1),RY(1),ISAVE(1),B(1),
1          T(1),ANS(10)
    MM=K+1
    DO 100 J=1,K
100 B(J)=0.0
        DO 110 J=1,K
            L1=K*(J-1)
            DO 110 I=1,K
                L=L1+I
110 B(J)=B(J)+RY(I)*RX(L)
            RM=0.0
            BO=0.0
            L1=ISAVE(MM)
            DO 120 I=1,K
                RM=RM+B(I)*RY(I)
                L=ISAVE(I)
                B(I)=B(I)*(STD(L1)/STD(L))
120 BO=BO+B(I)*XBAR(L)
            BO=XBAR(L1)-BO
            SSAR=RM*D(L1)
122 RM=SQRT(ABS(RM))
            SSDR=D(L1)-SSAR
            FN=N-K-1
            SY=SSDR/FN
            DO 130 J=1,K
                L1=K*(J-1)+J
                L=ISAVE(J)
125 SB(J)=SQRT(ABS((RX(L1)/D(L))*SY))
130 T(J)=B(J)/SB(J)

```

```

135 SY=SQRT(ABS(SY))
    FK=K
    SSARM=SSAR/FK
    SSDRM=SSDR/FN
    F=SSARM/SSDRM
    ANS(1)=BO
    ANS(2)=RM
    ANS(3)=SY
    ANS(4)=SSAR
    ANS(5)=FK
    ANS(6)=SSARM
    ANS(7)=SSDR
    ANS(8)=FN
    ANS(9)=SSDRM
    ANS(10)=F
    RETURN
    END

```

```

    SUBROUTINE DATA (M,D)
    DIMENSION D(10)
    COMMON MX,MY
    2 FORMAT(12F6.0)
    4 FORMAT(5X,F6.2,5X,F6.2,5X,F6.2,5X,F6.2,5X,F6.2,5X,
    1F6.2,5X,F6.2,5X,F6.2)
    R=1.0
    S=1.0
    READ(MY,2)(D(I),I=1,M)
    D(5)=R*D(5)+S*D(6)
    D(6)=D(4)/D(1)
    D(7)=D(4)/D(2)
    D(8)=D(1)+D(2)+D(3)+D(4)
    D(8)=ALOG(D(8))
    DO 3 I=1,M
    3 D(I)=ALOG(D(I))
    AA=EXP(D(1))
    AB=EXP(D(2))
    AC=EXP(D(3))
    AD=EXP(D(4))
    AE=EXP(D(5))
    AF=EXP(D(6))
    AG=EXP(D(7))
    AH=EXP(D(8))
    WRITE(MX,4)AA,AB,AC,AD,AE,AF,AG,AH
    RETURN
    END

```

APPENDIX C

PROGRAM STAFF AND SUBROUTINES

```

*NAME STAFF
*ONE WORD INTEGERS
*IOCS(CARD,1132PRINTER)
  DIMENSION T(40),C(40),B(40),S(40),AN(40),BP(10)
  DIMENSION RC(40),SC(40),ANC(40),BA(10),CC(40),TC(40)
  DIMENSION TX(4),CX(4),BX(4),SX(4)
  DIMENSION CAPT(25)
  DATA R0,R1,R2,R3/1.98389,2.37888,-0.85062,-0.82093/
  DATA V1,V2,V3/1.78226,1.71990,1.75169/
  DATA W1,W2,W3/0.05929,0.12304,0.03223/
  DATA FNR,SE,TV/34.,0.04034,2.036/
  READ(2,1)TITLE,NY
  N=4*NY+4
  M=4
  NR=N-M+1
  1  FORMAT(A1,I2)
  5  FORMAT(12F5.0)
  7  FORMAT(1H1)
  9  FORMAT(25X,I5,5F10.0)
  17 FORMAT(18X,'PD          S/T          S/C          P(UP)',7X,'P',
    17X,'P(LOW)',5X,'S/P',6X,'TC/P',/)
  19 FORMAT(15X,I5,7F10.2)
  160 FORMAT(28X,'QTR',7X,'T',9X,'C',8X,' P ',8X,'S',6X,
    1'TOTAL',/)
  501 FORMAT(////////,30X,'COMPARISON OF REQUIRED AND PROJECTE
    1D',/,35X,'LABOR BUDGETS FOR OPTION ',I1,',',/,42X,'LABO
    2RATORY ',A1,/)
  502 FORMAT(36X,'REQUIRED          PROJECTED',/23X,'FISCAL
    1  BUDGET          BUDGET          PER CENT',/,24X,'YEAF
    2  ($X1000)          ($X1000)          CHANGE',/)
  503 FORMAT(26X,I1,F16.0,F15.0,F12.0,/)
  504 FORMAT(////////,38X,'PROJECTED PERSONNEL STRENGTHS',/,
    141X,'LABORATORY ',A1,',', OPTION 'I1,/)
  505 FORMAT(////////,33X,'ANALYSIS OF PROJECTED PERSONNEL
    1 STRENGTHS',/,43X,'LABORATORY ',A1,',', OPTION 'I1,//
  506 FORMAT(//,41X,'DESIRED S/T RATIO IS ',F6.2,/,41X,'DES
    1IRED S/C RATIO IS ',F6.2)
  508 FORMAT(5X,40A1,////////)
  510 FORMAT(////////)
    DO 4 I=1,4
      4  READ(2,5) TX(I),CX(I),BX(I),SX(I)
        READ(2,5)AVT,AVC,AVB,AVS
        AVT=AVT/4.
        AVC=AVC/4.
        AVB=AVB/4.
        AVS=AVS/4.
        READ(2,5)(BP(I),I=1,NY)
  200 READ(2,5)(BA(I),I=1,NY)
    DO 350 LB=1,5
      READ(2,508)CAPT
      READ(2,5)DF,CF,A1,A2
    DO 300 LA=1,4
      NOP=LA
    DO 3 I=1,4

```

```

T(I)=TX(I)
C(I)=CX(I)
B(I)=BX(I)
3 S(I)=SX(I)
DO 6 I=1,4
TC(I)=T(I)*AVT
CC(I)=AVC*C(I)
BC(I)=AVB*B(I)
6 SC(I)=AVS*S(I)
WRITE(3,7)
WRITE(3,508)CAPT
WRITE(3,510)
WRITE(3,501)NOP,TITLE
WRITE(3,502)
DO 10 I=5,NR,4
KL=I/4
TF=(1.0+DF)**KL
ATT=TF*AVT
ATC=TF*AVC
ATB=TF*AVB
ATS=TF*AVS
K=I-1
KK=I+3
NBP=BP(KL)
DO 11 J=I,KK
T(J)=T(K)
C(J)=C(K)
IF(NBP)27,27,21
21 B(J)=BP(KL)
GO TO 28
27 B(J)=B(K)
28 S(J)=S(K)
TC(J)=ATT*T(J)
CC(J)=ATC*C(J)
BC(J)=ATB*B(J)
SC(J)=ATS*S(J)
AN(J)=T(J)+C(J)+B(J)+S(J)
11 ANC(J)=TC(J)+CC(J)+BC(J)+SC(J)
BT=0.0
DO 14 J=I,KK
14 BT=BT+ANC(J)
VF=(BA(KL)/BT)*100.-100.
WRITE(3,503)KL,BT,BA(KL),VF
C COMPARE REQUIRED BUDGET TO PROJECTED BUDGET
NBT=BA(KL)-BT
NVF=VF
IF(NVF)70,10,12
12 GO TO (20,30,20,30),NOP
20 VF=BA(KL)/BT
DO 22 J=I,KK
T(J)=T(J)*VF
T(J)=AINT(T(J))
C(J)=C(J)*VF

```



```

C(J)=AINT(C(J))
S(J)=S(J)*VF
S(J)=AINT(S(J))
TC(J)=ATT*T(J)
CC(J)=ATC*C(J)
BC(J)=ATB*B(J)
SC(J)=ATS*S(J)
AN(J)=T(J)+C(J)+B(J)+S(J)
22 ANC(J)=TC(J)+CC(J)+BC(J)+SC(J)
GO TO 10
C
C
OPTION 2. INCREASE LEVELS, MAINTAINING OR IMPROVING
S/T, S/C RATIO.
30 NBT=BA(KL)-BT
31 S1=S(I)/T(I)
S2=S(I)/C(I)
IF(S2-A2)35,35,32
32 DO 33 J=I, KK
33 C(J)=C(J)+1.0
NX=4.0*ATC
IF(NBT-NX)10,10,34
34 NBT=NBT-NX
GO TO 31
35 IF(S1-A1)46,46,36
36 DO 37 J=I, KK
37 T(J)=T(J)+1.0
NX=4.0*ATT
IF(NBT-NX)10,10,38
38 NBT=NBT-NX
GO TO 31
46 DO 47 J=I, KK
S(J)=S(J)+1.0
47 AN(J)=T(J)+C(J)+S(J)
NX=4.0*ATS
IF(NBT-NX)10,10,48
48 NBT=NBT-NX
GO TO 31
70 GO TO (20,140,71,100),NOP
71 NBT=BT-BA(KL)
XF=1.0-CF
74 NTC=0
DO 75 J=I, KK
JL=KK-J
JJ=I+JL
T(JJ)=T(JJ)*XF
T(JJ)=AINT(T(JJ))
C(JJ)=C(JJ)*XF
C(JJ)=AINT(C(JJ))
S(JJ)=S(JJ)*XF
S(JJ)=AINT(S(JJ))
TC(JJ)=T(JJ)*ATT
CC(JJ)=C(JJ)*ATC
SC(JJ)=S(JJ)*ATS
BC(JJ)=B(JJ)*ATB
AN(JJ)=T(JJ)+C(JJ)+B(JJ)+S(JJ)

```

```

ANC(JJ)=TC(JJ)+CC(JJ)+BC(JJ)+SC(JJ)
NTC=NTC+ANC(JJ)
IF(NBT-NTC)10,10,72
72 IF(JL)73,73,75
73 XF=XF-CF
GO TO 74
75 CONTINUE
C OPTION 4. DECREASE LEVELS ON A QUARTER BY QUARTER
C BASIS, AND BY MAINTAINING OR IMPROVING THE S/T, S/C
C RATIOS.
100 NBT=BT-BA(KL)
XF=1.0-CF
NS1=A1*T(I)
NS2=A2*C(I)
IF(NS1-NS2)101,101,110
101 DO 104 J=I, KK
JL=KK-J
JJ=I+JL
S(JJ)=S(JJ)-1.0
NX=ATS
IF(NBT-NX)10,10,102
102 NBT=NBT-NX
NS=S(JJ)
IF(NS-NS2)103,103,104
103 IF(NS-NS1)105,105,104
104 CONTINUE
GO TO 101
110 DO 115 J=I, KK
JL=KK-J
JJ=I+JL
S(JJ)=S(JJ)-1.0
NX=ATS
IF(NBT-NX)10,10,112
112 NBT=NBT-NX
NS=S(JJ)
IF(NS-NS1)114,114,115
114 IF(NS-NS2)105,105,115
115 CONTINUE
GO TO 110
105 NX=0
NT=BA(KL)
DO 107 J=I, KK
JL=KK-J
JJ=I+JL
S(JJ)=S(JJ)*XF
T(JJ)=T(JJ)*XF
C(JJ)=C(JJ)*XF
S(JJ)=AINT(S(JJ))
T(JJ)=AINT(T(JJ))
C(JJ)=AINT(C(JJ))
AN(JJ)=T(JJ)+C(JJ)+B(JJ)+S(JJ)
TC(JJ)=T(JJ)*ATT
CC(JJ)=C(JJ)*ATC
BC(JJ)=B(JJ)*ATB

```

```

SC(JJ)=S(JJ)*ATS
ANC(JJ)=TC(JJ)+CC(JJ)+BC(JJ)+SC(JJ)
NX=ANC(JJ)+NX
IF(NX-NT)10,10,106
106 XF=XF-CF
107 CONTINUE
140 NBT=BT-BA(KL)
141 S1=S(I)/T(I)
    S2=S(I)/C(I)
    IF(S2-A2)145,145,142
142 DO 143 J=I, KK
143 S(J)=S(J)-1.0
    NX=4.0*ATS
    IF(NBT-NX)10,10,144
144 NBT=NBT-NX
    GO TO 141
145 IF(S1-A1)146,146,142
146 DO 147 J=I, KK
    S(J)=S(J)-1.0
    T(J)=T(J)-1.0
    C(J)=C(J)-1.0
147 AN(J)=T(J)+C(J)+B(J)+S(J)
    NX=4.0*(ATS+ATT+ATC)
    IF(NBT-NX)10,10,148
148 NBT=NBT-NX
    GO TO 141
10 CONTINUE
C   COMPUTE MOVING AVERAGES FOR LEVELS AND SALARIES,
C   LAGGING THE RESPECTIVE DATA SERIES PROPERLY. COMPUTE
C   THE PREDICTED OUTPUT AND COST PER UNIT OUTPUT.
C   PRINT OUTPUT PLOTS.
    WRITE(3,7)
    WRITE(3,508)CAPT
    WRITE(3,510)
    WRITE(3,504)TITLE,NOP
    WRITE(3,160)
    DO 8 I=5,N
      J=I-4
      8 WRITE(3,9)J,T(I),C(I),B(I),S(I),AN(I)
        WRITE(3,7)
        CALL MVAVG(T,N,M)
        CALL MVAVG(C,N,M)
        CALL MVAVG(B,N,M)
        CALL MVAVG(S,N,M)
        CALL MVAVG(TC,N,M)
        CALL MVAVG(CC,N,M)
        CALL MVAVG(BC,N,M)
        CALL MVAVG(SC,N,M)
        WRITE(3,508)CAPT
        WRITE(3,510)
        WRITE(3,505)TITLE,NOP
        WRITE(3,17)
        NQ=NR-4
        DO 51 I=1,NQ

```

```

J=I+2
K=I+4
TW=T(J)
CW=C(K)
BW=B(J)
SW=S(J)
ANW=TW+CW+BW+SW
TCW=TC(J)
CCW=CC(K)
BCW=BC(J)
SCW=SC(J)
ANCW=TCW+CCW+BCW+SCW
S1=ALOG(ANW)
S1=ALOG(S1)
S2=SW/TW
S2=ALOG(S2)
S3=SW/CW
S3=ALOG(S3)
P=R0+R1*S1+R2*S2+R3*S3
Q=(S1-V1)**2/(FNR*W1**2)+(S2-V2)**2/(FNR*W2**2)
Q=Q+(S3-V3)**2/(FNR*W3**2)+1.0
Q=1.0+(1.0/FNR)*Q
Q=TV*SE*SQRT(Q)
PUP=P+Q
PLOW=P-Q
P=EXP(P)
PUP=EXP(PUP)
PLOW=EXP(PLOW)
S2 = EXP(S2)
S3=EXP(S3)
PC=ANCW/P
PTS=SCW/P
51 WRITE(3,19) I,S2,S3,PUP,P,PLOW,PTS,PC
GO TO (53,52,53,52),NOP
52 WRITE(3,506)A1,A2
53 CONTINUE
300 CONTINUE
350 CONTINUE
GO TO 200
600 WRITE(3,7)
STOP
END
SUBROUTINE MVAVG(A,N,M)
DIMENSION A(1)
FM=M
NR=N-M+1
DO 2 I=1,NR
XX=0.0
DO 3 J=1,M
L=I+J-1
3 XX=XX+A(L)
2 A(I)=XX/FM
RETURN
END

```

```

SUBROUTINE PLOT(A,N,M)
  DIMENSION OUT(51),YPR(11),ANG(9),A(1)
  2  FORMAT(1X,F11.0,2X,51A1)
  3  FORMAT(2X)
  5  FORMAT(10A1)
  7  FORMAT(14X,'. . . . .')
  8  FORMAT(/,11X,11F5.1)
  9  FORMAT(1H1,//////////)
  WRITE(3,9)
  NLL=16
  DO 15 I=1,N
  DO 14 J=I,N
  IF(A(I)-A(J))14,14,11
11  L=I-N
  LL=J-N
  DO 12 K=1,M
  L=L+N
  LL=LL+N
  F=A(L)
  A(L)=A(LL)
12  A(LL)=F
14  CONTINUE
15  CONTINUE
  READ(2,5) BLANK,(ANG(I),I=1,9)
  X=(A(N)-A(1))/(FLOAT(NLL-1))
  M1=N+1
  M2=M*N
  YMIN=A(M1)
  YMAX=YMIN
  DO 40 J=M1,M2
  IF(A(J)-YMIN)28,26,26
26  IF(A(J)-YMAX)40,40,30
28  YMIN=A(J)
  GO TO 40
30  YMAX = A(J)
40  CONTINUE
  Y=(YMAX-YMIN)/50.
  XB=A(1)
  L=1
  MYX=M-1
  I=1
45  F=I-1
  XPR=XB+F*X
  IF(A(L)-XPR)50,50,70
50  DO 55 IX=1,51
55  OUT(IX)=BLANK
  DO 60 J=1,MYX
  LL=L+J*N
  JP=((A(LL)-YMIN)/Y)+1.0
  OUT(JP)=ANG(J)
60  CONTINUE
  WRITE(3,2)XPR,(OUT(IZ),IZ=1,51)
  L=L+1
  GO TO 80
70  WRITE(3,3)

```

```
80 I=I+1
   IF(I-NLL)45,84,86
84 XPR=A(N)
   GO TO 50
86 WRITE(3,7)
   YPR(1)=YMIN
   DO 90 KN=1,9
90 YPR(KN+1)=YPR(KN)+Y*5.0
   YPR(11)=YMAX
   WRITE(3,8)(YPR(IP),IP=1,11)
   RETURN
   END
```

APPENDIX D

PROGRAM STAFF INPUT

// XEQ STAFF

A 5

15. 15. 9. 97.

14. 14. 9. 90.

19. 14. 9. 96.

22. 16. 7. 95.

8.7 6.8 12.3 18.9

0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

2544.2939.3393.3921.4531.

LAB A HIGH S/T, HIGH S/C CASE I

0.06 0.01 6.63 6.69

1234

1234

LAB A LOW S/T, LOW S/C CASE I

0.06 0.01 5.04 5.37

1234

1234

LAB A AVG S/T, AVG S/C CASE I

0.06 0.01 5.52 5.3

1234

1234

LAB A HIGH S/T, LOW S/C CASE I

0.06 0.01 6.63 5.37

1234

1234

LAB A LOW S/T, HIGH S/C CASE I

0.06 0.01 5.04 6.69

1234

1234

2081.1975.1877.1783.1694.

LAB A HIGH S/T, HIGH S/C CASE II

0.06 0.01 6.63 6.69

1234

1234

LAB A LOW S/T, LOW S/C CASE II

0.06 0.01 5.04 5.37

1234

1234

LAB A AVG S/T, AVG S/C CASE II

0.06 0.01 5.52 5.3

1234

1234

LAB A HIGH S/T, LOW S/C CASE II

0.06 0.01 6.63 5.37

1234

1234

A LOW S/T, HIGH S/C CASE II

0.06 0.01 5.04 6.69

1234

1234

2544.2399.2789.2639.3055.

LAB A HIGH S/T, HIGH S/C CASE III

0.06 0.01 6.63 6.69

1234

1234

LAB A LOW S/T, LOW S/C CASE III

0.06 0.01 5.04 5.37

1234

1234

LAB A AVG S/T, AVG S/C CASE III

0.06 0.01 5.52 5.3

1234

1234

LAB A HIGH S/T, LOW S/C CASE III

0.06 0.01 6.63 5.37

1234

1234

LAB A LOW S/T, HIGH S/C CASE III

0.06 0.01 5.04 6.69

1234

1234

// JOB

// XEQ STAFF

B 5

40. 34. 7. 228.

39. 33. 8. 228.

38. 32. 8. 223.

37. 31. 8. 219.

8.7 6.8 12.3 18.9

0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

5563.6444.7498.8723.10127

LAB B HIGH S/T, HIGH S/C CASE I

0.06 0.01 6.94 7.

1234

1234

LAB B LOW S/T, LOW S/C CASE I

0.06 0.01 5.96 6.02

1234

1234

LAB B AVG S/T, AVG S/C CASE I

0.06 0.01 6.09 6.09

1234

1234

LAB B HIGH S/T, LOW S/C CASE I

0.06 0.01 6.94 6.02

1234

1234

LAB B LOW S/T, HIGH S/C CASE I

0.06 0.01 5.96 7.

1234

1234

4550.4301.4089.3887.3693.

LAB B HIGH S/T, HIGH S/C CASE II
 0.06 0.01 6.94 7.
 1234
 1234
 LAB B LOW S/T, LOW S/C CASE II
 0.06 0.01 5.96 6.02
 1234
 1234
 LAB B AVG S/T, AVG S/C CASE II
 0.06 0.01 6.09 6.09
 1234
 1234
 LAB B HIGH S/T, LOW S/C CASE-II
 0.06 0.01 6.94 6.02
 1234
 1234
 LAB B LOW S/T, HIGH S/C CASE II
 0.06 0.01 5.96 7.
 1234
 1234
 5563.5271.6119.5810.6769.
 LAB B HIGH S/T, HIGH S/C CASE III
 0.06 0.01 6.94 7.
 1234
 1234
 LAB B LOW S/T, LOW S/C CASE III
 0.06 0.01 5.96 6.02
 1234
 1234
 LAB B AVG S/T, AVG S/C CASE III
 0.06 0.01 6.09 6.09
 1234
 1234
 LAB B HIGH S/T, LOW S/C CASE III
 0.06 0.01 6.94 6.02
 1234
 1234
 LAB B LOW S/T, HIGH S/C CASE III
 0.06 0.01 5.96 7.
 1234
 1234
 // JOB
 // XEQ STAFF
 A 9
 5. 6. 2. 34.
 5. 8. 2. 35.
 6. 6. 2. 38.
 8. 7. 3. 39.
 9. 6.4 11.4 17.6
 3. 4. 5. 6. 7. 8. 7. 7. 9.
 958. 1208.1529.1406.1560.1757.1901.2044.2095.
 LAB A CASE IV AVG S/T, AVG S/C
 0.01 5.52 5.3

1234
1234
// JOB
// XEQ STAFF
B 9
19. 24. 2. 127.
25. 24. 2. 138.
29. 26. 2. 157.
23. 28. 2. 148.
9. 6.4 11.4 17.6
2. 4. 5. 6. 6. 5. 6. 6. 8.
3889.5393.5845.6052.6400.6002.5759.5765.5277.
LAB B CASE IV AVG S/T, AVG S/C
0.01 6.09 6.09
1234
1234

APPENDIX E

SAMPLE OUTPUT FOR PROGRAM STAFF

COMPARISON OF REQUIRED AND PROJECTED
LABOR BUDGETS FOR OPTION 1,
LABORATORY A

FISCAL YEAR	REQUIRED BUDGET (\$X1000)	PROJECTED BUDGET (\$X1000)	PER CENT CHANGE
1	2312.	2544.	10.
2	2669.	2939.	10.
3	3083.	3393.	10.
4	3561.	3921.	10.
5	4111.	4531.	10.

PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 1

QTR	T	C	P	S	TOTAL
1	24.	17.	7.	104.	152.
2	24.	17.	7.	104.	152.
3	24.	17.	7.	104.	152.
4	24.	17.	7.	104.	152.
5	26.	18.	7.	114.	165.
6	26.	18.	7.	114.	165.
7	26.	18.	7.	114.	165.
8	26.	18.	7.	114.	165.
9	28.	19.	7.	125.	179.
10	28.	19.	7.	125.	179.
11	28.	19.	7.	125.	179.
12	28.	19.	7.	125.	179.
13	30.	20.	7.	137.	194.
14	30.	20.	7.	137.	194.
15	30.	20.	7.	137.	194.
16	30.	20.	7.	137.	194.
17	33.	22.	7.	150.	212.
18	33.	22.	7.	150.	212.
19	33.	22.	7.	150.	212.
20	33.	22.	7.	150.	212.

ANALYSIS OF PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 1

PD	S/T	S/C	P(UP)	P	P(LOW)	S/P	TC/P
1	4.48	5.86	23.60	21.70	19.96	22.39	27.19
2	4.32	5.89	24.44	22.47	20.67	22.37	27.15
3	4.33	5.94	24.50	22.53	20.72	23.11	28.02
4	4.34	5.99	24.49	22.52	20.71	24.06	29.12
5	4.35	6.05	24.48	22.51	20.70	25.00	30.22
6	4.37	6.10	24.47	22.50	20.69	25.95	31.31
7	4.38	6.16	24.47	22.50	20.69	26.89	32.40
8	4.40	6.22	24.40	22.43	20.63	28.06	33.75
9	4.42	6.28	24.33	22.38	20.57	29.23	35.10
10	4.44	6.35	24.28	22.32	20.52	30.40	36.46
11	4.46	6.41	24.22	22.27	20.48	31.57	37.81
12	4.49	6.48	24.11	22.17	20.38	33.00	39.45
13	4.51	6.54	24.01	22.07	20.29	34.44	41.09
14	4.54	6.53	24.17	22.22	20.42	35.49	42.31
15	4.56	6.52	24.32	22.36	20.56	36.54	43.51
16	4.56	6.52	24.60	22.62	20.79	37.57	44.72
17	4.55	6.52	24.87	22.87	21.02	38.59	45.90

PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 2

QTR	T	C	P	S	TOTAL
1	22.	16.	7.	107.	145.
2	22.	16.	7.	107.	145.
3	22.	16.	7.	107.	145.
4	22.	16.	7.	107.	145.
5	22.	18.	7.	118.	158.
6	22.	18.	7.	118.	158.
7	22.	18.	7.	118.	158.
8	22.	18.	7.	118.	158.
9	22.	20.	7.	130.	172.
10	22.	20.	7.	130.	172.
11	22.	20.	7.	130.	172.
12	22.	20.	7.	130.	172.
13	22.	22.	7.	143.	187.
14	22.	22.	7.	143.	187.
15	22.	22.	7.	143.	187.
16	22.	22.	7.	143.	187.
17	24.	24.	7.	156.	204.
18	24.	24.	7.	156.	204.
19	24.	24.	7.	156.	204.
20	24.	24.	7.	156.	204.

ANALYSIS OF PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 2

PD	S/T	S/C	P(UP)	P	P(LOW)	S/P	TC/P
1	4.76	6.32	21.03	19.33	17.78	23.96	29.14
2	4.72	6.30	21.48	19.75	18.16	23.74	28.89
3	4.86	6.29	21.72	19.51	17.94	24.57	29.66
4	4.98	6.27	21.04	19.34	17.79	25.78	31.19
5	5.11	6.24	20.86	19.18	17.64	27.70	32.74
6	5.23	6.22	20.68	19.02	17.49	28.65	34.57
7	5.36	6.21	20.51	18.86	17.34	30.11	36.02
8	5.49	6.20	20.28	18.65	17.16	31.73	37.84
9	5.63	6.19	20.07	18.46	16.97	33.57	39.69
10	5.77	6.19	19.86	18.26	16.80	35.03	41.57
11	5.90	6.19	19.66	18.08	16.63	36.72	43.49
12	6.05	6.19	19.41	17.85	16.42	38.74	45.75
13	6.20	6.20	19.18	17.64	16.22	40.80	48.05
14	6.35	6.21	18.95	17.43	16.03	42.88	50.40
15	6.49	6.21	18.73	17.23	15.84	45.00	52.78
16	6.49	6.22	18.90	17.38	15.98	46.45	54.34
17	6.49	6.22	19.06	17.53	16.12	47.88	55.88

DESIRED S/T RATIO IS 6.63
DESIRED S/C RATIO IS 6.69

PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 3

QTR	T	C	P	S	TOTAL
1	24.	17.	7.	104.	152.
2	24.	17.	7.	104.	152.
3	24.	17.	7.	104.	152.
4	24.	17.	7.	104.	152.
5	26.	18.	7.	114.	165.
6	26.	18.	7.	114.	165.
7	26.	18.	7.	114.	165.
8	26.	18.	7.	114.	165.
9	28.	19.	7.	125.	179.
10	28.	19.	7.	125.	179.
11	28.	19.	7.	125.	179.
12	28.	19.	7.	125.	179.
13	30.	20.	7.	137.	194.
14	30.	20.	7.	137.	194.
15	30.	20.	7.	137.	194.
16	30.	20.	7.	137.	194.
17	33.	22.	7.	150.	212.
18	33.	22.	7.	150.	212.
19	33.	22.	7.	150.	212.
20	33.	22.	7.	150.	212.

ANALYSIS OF PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 3

PD	S/T	S/C	P(UP)	P	P(LOW)	S/P	TC/P
1	4.48	5.86	23.60	21.70	19.96	22.39	27.19
2	4.32	5.89	24.44	22.47	20.67	22.37	27.15
3	4.33	5.94	24.50	22.53	20.72	23.11	28.02
4	4.34	5.99	24.49	22.52	20.71	24.06	29.12
5	4.35	6.05	24.48	22.51	20.70	25.00	30.22
6	4.37	6.10	24.47	22.50	20.69	25.95	31.31
7	4.38	6.16	24.47	22.50	20.69	26.89	32.40
8	4.40	6.22	24.40	22.43	20.63	28.06	33.75
9	4.42	6.28	24.33	22.38	20.57	29.23	35.10
10	4.44	6.35	24.28	22.32	20.52	30.40	36.46
11	4.46	6.41	24.22	22.27	20.48	31.57	37.81
12	4.49	6.48	24.11	22.17	20.38	33.00	39.45
13	4.51	6.54	24.01	22.07	20.29	34.44	41.09
14	4.54	6.53	24.17	22.22	20.42	35.49	42.31
15	4.56	6.52	24.32	22.36	20.56	36.54	43.51
16	4.56	6.52	24.60	22.62	20.79	37.57	44.72
17	4.55	6.52	24.87	22.87	21.02	38.59	45.90

PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 4

QTR	T	C	P	S	TOTAL
1	22.	16.	7.	107.	145.
2	22.	16.	7.	107.	145.
3	22.	16.	7.	107.	145.
4	22.	16.	7.	107.	145.
5	22.	18.	7.	118.	158.
6	22.	18.	7.	118.	158.
7	22.	18.	7.	118.	158.
8	22.	18.	7.	118.	158.
9	22.	20.	7.	130.	172.
10	22.	20.	7.	130.	172.
11	22.	20.	7.	130.	172.
12	22.	20.	7.	130.	172.
13	22.	22.	7.	143.	187.
14	22.	22.	7.	143.	187.
15	22.	22.	7.	143.	187.
16	22.	22.	7.	143.	187.
17	24.	24.	7.	156.	204.
18	24.	24.	7.	156.	204.
19	24.	24.	7.	156.	204.
20	24.	24.	7.	156.	204.

ANALYSIS OF PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 4

PD	S/T	S/C	P(UP)	P	P(LOW)	S/P	TC/P
1	4.76	6.32	21.03	19.33	17.78	23.96	29.14
2	4.72	6.30	21.48	19.75	18.16	23.74	28.89
3	4.86	6.29	21.22	19.51	17.94	24.37	29.66
4	4.98	6.27	21.04	19.34	17.79	25.78	31.19
5	5.11	6.24	20.86	19.18	17.64	27.20	32.74
6	5.23	6.22	20.68	19.02	17.49	28.65	34.37
7	5.36	6.21	20.51	18.86	17.34	30.11	36.02
8	5.49	6.20	20.28	18.65	17.16	31.73	37.84
9	5.63	6.19	20.07	18.46	16.97	33.37	39.69
10	5.77	6.19	19.86	18.26	16.80	35.03	41.57
11	5.90	6.19	19.66	18.08	16.63	36.72	43.48
12	6.05	6.19	19.41	17.85	16.42	38.74	45.75
13	6.20	6.20	19.18	17.64	16.22	40.80	48.05
14	6.35	6.21	18.95	17.43	16.03	42.88	50.40
15	6.49	6.21	18.73	17.23	15.84	45.00	52.78
16	6.49	6.22	18.90	17.38	15.98	46.45	54.34
17	6.49	6.22	19.06	17.53	16.12	47.88	55.88

DESIRED S/T RATIO IS 6.63
DESIRED S/C RATIO IS 6.69

COMPARISON OF REQUIRED AND PROJECTED
LABOR BUDGETS FOR OPTION 1,
LABORATORY A

FISCAL YEAR	REQUIRED BUDGET (\$X1000)	PROJECTED BUDGET (\$X1000)	PER CENT CHANGE
1	2312.	2081.	-10.
2	2194.	1975.	-10.
3	2086.	1877.	-10.
4	1981.	1783.	-10.
5	1882.	1694.	-9.

PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTICN 1

QTR	T	C	P	S	TOTAL
1	19.	14.	7.	85.	125.
2	19.	14.	7.	85.	125.
3	19.	14.	7.	85.	125.
4	19.	14.	7.	85.	125.
5	17.	12.	7.	76.	112.
6	17.	12.	7.	76.	112.
7	17.	12.	7.	76.	112.
8	17.	12.	7.	76.	112.
9	15.	10.	7.	68.	100.
10	15.	10.	7.	68.	100.
11	15.	10.	7.	68.	100.
12	15.	10.	7.	68.	100.
13	13.	8.	7.	61.	89.
14	13.	8.	7.	61.	89.
15	13.	8.	7.	61.	89.
16	13.	8.	7.	61.	89.
17	11.	7.	7.	54.	79.
18	11.	7.	7.	54.	79.
19	11.	7.	7.	54.	79.
20	11.	7.	7.	54.	79.

ANALYSIS OF PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 1

PD	S/T	S/C	P(UP)	P	P(LOW)	S/P	TC/P
1	4.56	6.44	20.41	18.76	17.24	23.36	28.33
2	4.43	6.48	20.57	18.91	17.38	22.81	27.68
3	4.47	6.53	19.96	18.34	16.86	23.20	28.14
4	4.47	6.61	19.51	17.92	16.47	23.43	28.44
5	4.47	6.70	19.04	17.49	16.07	23.69	28.78
6	4.47	6.80	18.56	17.05	15.66	23.98	29.15
7	4.47	6.90	18.07	16.60	15.24	24.30	29.55
8	4.48	7.04	17.49	16.06	14.75	24.78	30.16
9	4.49	7.19	16.90	15.51	14.24	25.33	30.83
10	4.51	7.36	16.29	14.95	13.72	25.93	31.57
11	4.53	7.55	15.67	14.37	13.18	26.61	32.39
12	4.56	7.79	14.97	13.72	12.57	27.54	33.52
13	4.60	8.06	14.25	13.05	11.95	28.59	34.79
14	4.64	8.09	13.89	12.72	11.65	28.95	35.25
15	4.69	8.13	13.53	12.39	11.34	29.35	35.76
16	4.73	8.17	13.16	12.05	11.03	29.71	36.23
17	4.79	8.21	12.78	11.70	10.71	30.12	36.76

PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 2

QTR	T	C	P	S	TOTAL
1	18.	12.	7.	85.	122.
2	18.	12.	7.	85.	122.
3	18.	12.	7.	85.	122.
4	18.	12.	7.	85.	122.
5	17.	11.	7.	76.	114.
6	17.	11.	7.	76.	114.
7	17.	11.	7.	76.	114.
8	17.	11.	7.	76.	114.
9	16.	10.	7.	67.	105.
10	16.	10.	7.	67.	105.
11	16.	10.	7.	67.	105.
12	16.	10.	7.	67.	105.
13	14.	8.	7.	59.	88.
14	14.	8.	7.	59.	88.
15	14.	8.	7.	59.	88.
16	14.	8.	7.	59.	88.
17	14.	8.	7.	53.	83.
18	14.	8.	7.	53.	83.
19	14.	8.	7.	53.	83.
20	14.	8.	7.	53.	83.

ANALYSIS OF PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 2

PD	S/T	S/C	P(UP)	P	P(LOW)	S/P	TC/P
1	4.68	7.52	17.46	16.02	14.70	28.92	35.17
2	4.60	7.44	17.62	16.16	14.83	29.01	35.18
3	4.72	7.39	17.09	15.68	14.39	30.32	36.66
4	4.66	7.35	17.15	15.74	14.44	29.83	35.96
5	4.59	7.31	17.22	15.80	14.50	29.32	35.26
6	4.53	7.27	17.29	15.87	14.56	28.81	34.63
7	4.47	7.23	17.37	15.94	14.63	28.30	33.99
8	4.40	7.19	17.45	16.02	14.71	27.79	33.46
9	4.33	7.14	17.55	16.11	14.79	27.27	32.92
10	4.26	7.28	17.27	15.85	14.54	27.35	33.11
11	4.18	7.44	16.97	15.57	14.28	27.46	33.34
12	4.19	7.64	16.33	14.97	13.72	28.09	34.22
13	4.19	7.87	15.66	14.35	13.15	28.81	35.21
14	4.20	7.62	15.82	14.51	13.30	28.02	34.32
15	4.21	7.37	15.99	14.67	13.45	27.23	33.43
16	4.10	7.18	16.54	15.17	13.92	25.89	31.80
17	3.99	6.99	17.12	15.71	14.42	24.58	30.21

DESIRED S/T RATIO IS 6.63
DESIRED S/C RATIO IS 6.59

PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 3

QTR	T	C	P	S	TOTAL
1	22.	16.	7.	95.	140.
2	22.	16.	7.	95.	140.
3	22.	16.	7.	95.	140.
4	21.	15.	7.	94.	137.
5	21.	15.	7.	94.	137.
6	21.	15.	7.	94.	137.
7	21.	15.	7.	94.	137.
8	20.	14.	7.	93.	134.
9	20.	14.	7.	93.	134.
10	20.	14.	7.	93.	134.
11	19.	13.	7.	92.	131.
12	19.	13.	7.	92.	131.
13	19.	13.	7.	92.	131.
14	19.	13.	7.	92.	131.
15	18.	12.	7.	91.	128.
16	18.	12.	7.	91.	128.
17	18.	12.	7.	91.	128.
18	18.	12.	7.	91.	128.
19	17.	11.	7.	90.	125.
20	17.	11.	7.	90.	125.

ANALYSIS OF PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 3

PD	S/T	S/C	P(UP)	P	P(LOW)	S/P	TC/P
1	4.48	6.04	22.51	20.70	19.03	22.38	27.20
2	4.31	6.12	22.96	21.11	19.41	22.21	26.98
3	4.35	6.21	22.48	20.67	19.00	22.95	27.85
4	4.39	6.29	22.00	20.23	18.60	23.74	28.76
5	4.43	6.38	21.53	19.79	18.19	24.56	29.72
6	4.47	6.48	21.05	19.35	17.79	25.41	30.71
7	4.51	6.57	20.58	18.92	17.39	26.30	31.74
8	4.56	6.79	19.81	18.20	16.72	27.67	33.32
9	4.60	6.90	19.35	17.77	16.33	28.68	34.48
10	4.69	6.99	18.74	17.21	15.81	29.89	35.87
11	4.74	7.11	18.28	16.79	15.42	30.99	37.14
12	4.79	7.23	17.83	16.37	15.03	32.17	38.50
13	4.84	7.35	17.39	15.96	14.65	33.40	39.92
14	4.89	7.48	16.94	15.55	14.26	34.69	41.39
15	4.94	7.62	16.50	15.14	13.88	36.04	42.94
16	4.99	7.76	16.07	14.73	13.51	37.49	44.60
17	5.05	7.91	15.63	14.33	13.13	39.00	46.33

PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 4

QTR	T	C	P	S	TOTAL
1	22.	16.	7.	95.	140.
2	22.	16.	7.	95.	140.
3	22.	16.	7.	95.	140.
4	21.	15.	7.	93.	136.
5	21.	15.	7.	93.	136.
6	21.	15.	7.	93.	136.
7	21.	15.	7.	93.	136.
8	20.	14.	7.	91.	132.
9	20.	14.	7.	91.	132.
10	20.	14.	7.	91.	132.
11	20.	14.	7.	91.	132.
12	19.	13.	7.	89.	128.
13	19.	13.	7.	87.	128.
14	19.	13.	7.	87.	128.
15	19.	13.	7.	87.	128.
16	18.	12.	7.	85.	122.
17	18.	12.	7.	81.	122.
18	18.	12.	7.	81.	122.
19	18.	12.	7.	81.	122.
20	17.	11.	7.	79.	114.

ANALYSIS OF PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 4

PD	S/T	S/C	P(UP)	P	P(Low)	S/P	TC/P
1	4.48	6.04	22.51	20.70	19.03	22.38	27.20
2	4.31	6.12	22.96	21.11	19.41	22.21	26.98
3	4.34	6.19	22.56	20.74	19.07	22.81	27.69
4	4.37	6.26	22.16	20.37	18.73	23.44	28.43
5	4.39	6.33	21.76	20.00	18.39	24.10	29.20
6	4.42	6.41	21.36	19.63	18.05	24.78	30.00
7	4.45	6.49	20.96	19.26	17.70	25.48	30.83
8	4.48	6.57	20.55	18.89	17.36	26.23	31.70
9	4.51	6.65	20.15	18.52	17.02	27.00	32.60
10	4.54	6.74	19.75	18.15	16.68	27.80	33.53
11	4.58	6.83	19.36	17.78	16.34	28.63	34.50
12	4.58	6.88	19.10	17.54	16.11	29.29	35.26
13	4.59	6.94	18.84	17.30	15.89	29.97	36.04
14	4.60	6.99	18.57	17.06	15.66	30.67	36.85
15	4.61	7.06	18.31	16.81	15.44	31.21	37.50
16	4.59	7.08	18.18	16.69	15.33	31.53	37.88
17	4.57	7.10	18.05	16.57	15.21	31.86	38.28

DESIRED S/T RATIO IS 6.63
DESIRED S/C RATIO IS 6.69

COMPARISON OF REQUIRED AND PROJECTED
LABOR BUDGETS FOR OPTION 1,
LABORATORY A

FISCAL YEAR	REQUIRED BUDGET (\$X1000)	PROJECTED BUDGET (\$X1000)	PER CENT CHANGE
1	2312.	2544.	10.
2	2669.	2399.	-10.
3	2535.	2789.	10.
4	2932.	2639.	-10.
5	2777.	3055.	10.

PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 1

QTR	T	C	P	S	TOTAL
1	24.	17.	7.	104.	152.
2	24.	17.	7.	104.	152.
3	24.	17.	7.	104.	152.
4	24.	17.	7.	104.	152.
5	21.	15.	7.	93.	136.
6	21.	15.	7.	93.	136.
7	21.	15.	7.	93.	136.
8	21.	15.	7.	93.	136.
9	23.	16.	7.	102.	148.
10	23.	16.	7.	102.	148.
11	23.	16.	7.	102.	148.
12	23.	16.	7.	102.	148.
13	20.	14.	7.	91.	132.
14	20.	14.	7.	91.	132.
15	20.	14.	7.	91.	132.
16	20.	14.	7.	91.	132.
17	22.	15.	7.	100.	144.
18	22.	15.	7.	100.	144.
19	22.	15.	7.	100.	144.
20	22.	15.	7.	100.	144.

ANALYSIS OF PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 1

PD	S/T	S/C	P(UP)	P	P(LOW)	S/P	TC/P
1	4.48	5.86	23.60	21.70	19.96	22.39	27.19
2	4.32	6.16	23.51	21.62	19.87	23.25	28.16
3	4.33	6.49	22.67	20.83	19.15	24.99	30.16
4	4.35	6.53	22.20	20.40	18.75	25.19	30.41
5	4.37	6.56	21.71	19.96	18.34	25.41	30.69
6	4.40	6.27	22.17	20.38	18.74	24.55	29.73
7	4.42	5.99	22.63	20.81	19.14	23.71	28.81
8	4.43	6.04	22.72	20.89	19.21	24.59	29.82
9	4.43	6.09	22.80	20.96	19.28	25.45	30.83
10	4.43	6.43	21.96	20.19	18.56	27.42	33.10
11	4.43	6.79	21.15	19.44	17.86	29.52	35.51
12	4.46	6.84	20.66	18.98	17.44	29.81	35.87
13	4.48	6.89	20.16	18.52	17.01	30.14	36.28
14	4.51	6.57	20.58	18.92	17.39	29.09	35.11
15	4.54	6.27	21.01	19.32	17.76	28.09	33.99
16	4.54	6.32	21.12	19.42	17.85	29.10	35.16
17	4.54	6.36	21.23	19.52	17.94	30.10	36.32

PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 2

QTR	T	C	P	S	TOTAL
1	22.	16.	7.	107.	145.
2	22.	16.	7.	107.	145.
3	22.	16.	7.	107.	145.
4	22.	16.	7.	107.	145.
5	20.	14.	7.	94.	140.
6	20.	14.	7.	94.	140.
7	20.	14.	7.	94.	140.
8	20.	14.	7.	94.	140.
9	20.	16.	7.	105.	141.
10	20.	16.	7.	105.	141.
11	20.	16.	7.	105.	141.
12	20.	16.	7.	105.	141.
13	17.	13.	7.	92.	129.
14	17.	13.	7.	92.	129.
15	17.	13.	7.	92.	129.
16	17.	13.	7.	92.	129.
17	17.	16.	7.	103.	136.
18	17.	16.	7.	103.	136.
19	17.	16.	7.	103.	136.
20	17.	16.	7.	103.	136.

ANALYSIS OF PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 2

PD	S/T	S/C	P(UP)	P	P(LOW)	S/P	TC/P
1	4.76	6.32	21.03	19.33	17.78	23.96	29.14
2	4.72	6.70	20.35	18.70	17.19	25.07	30.51
3	4.86	7.13	19.05	17.50	16.07	27.18	33.08
4	4.82	7.15	18.88	17.33	15.92	28.77	34.81
5	4.78	7.17	18.70	17.17	15.76	30.39	36.58
6	4.74	6.70	19.68	18.09	16.62	30.12	36.03
7	4.69	6.26	20.73	19.06	17.52	29.80	35.43
8	4.83	6.24	20.52	18.87	17.35	29.58	35.23
9	4.97	6.21	20.32	18.69	17.18	29.34	35.01
10	5.11	6.70	18.80	17.28	15.88	31.17	37.38
11	5.24	7.24	17.39	15.96	14.66	33.12	39.94
12	5.28	7.39	16.72	15.35	14.09	36.04	43.30
13	5.32	7.57	16.04	14.72	13.50	39.24	46.99
14	5.36	6.92	16.93	15.55	14.29	38.69	46.03
15	5.41	6.34	17.84	16.40	15.08	38.18	45.13
16	5.57	6.21	17.92	16.48	15.15	37.31	44.10
17	5.73	6.09	17.99	16.55	15.22	36.49	43.12

DESIRED S/T RATIO IS 6.63
DESIRED S/C RATIO IS 6.69

PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 3

QTR	T	C	P	S	TOTAL
1	24.	17.	7.	104.	152.
2	24.	17.	7.	104.	152.
3	24.	17.	7.	104.	152.
4	24.	17.	7.	104.	152.
5	24.	17.	7.	104.	152.
6	24.	17.	7.	104.	152.
7	24.	17.	7.	104.	152.
8	23.	16.	7.	102.	148.
9	23.	16.	7.	102.	148.
10	23.	16.	7.	102.	148.
11	23.	16.	7.	102.	148.
12	23.	16.	7.	102.	148.
13	23.	16.	7.	102.	148.
14	23.	16.	7.	102.	148.
15	23.	16.	7.	102.	148.
16	22.	15.	7.	100.	144.
17	22.	15.	7.	100.	144.
18	22.	15.	7.	100.	144.
19	22.	15.	7.	100.	144.
20	22.	15.	7.	100.	144.

ANALYSIS OF PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 3

PD	S/T	S/C	P(UP)	P	P(LOW)	S/P	TC/P
1	4.48	5.86	23.60	21.70	19.96	22.39	27.19
2	4.32	5.98	24.13	22.19	20.40	22.66	27.48
3	4.33	6.11	23.89	21.97	20.20	23.70	28.70
4	4.33	6.11	23.89	21.97	20.20	24.06	29.13
5	4.33	6.20	23.58	21.68	19.94	24.73	29.92
6	4.33	6.30	23.28	21.40	19.65	25.42	30.73
7	4.35	6.36	22.90	21.05	19.35	26.09	31.52
8	4.38	6.43	22.52	20.70	19.03	26.80	32.34
9	4.40	6.40	22.44	20.63	18.97	27.15	32.77
10	4.43	6.37	22.36	20.56	18.90	27.51	33.20
11	4.43	6.37	22.36	20.56	18.90	27.91	33.67
12	4.43	6.37	22.36	20.56	18.90	28.33	34.18
13	4.43	6.47	22.06	20.28	18.64	29.14	35.14
14	4.43	6.58	21.76	20.00	18.38	29.98	36.12
15	4.46	6.65	21.38	19.65	18.06	30.80	37.08
16	4.48	6.73	21.00	19.30	17.73	31.67	38.09
17	4.51	6.69	20.92	19.23	17.67	32.10	38.60

PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 4

QTR	T	C	P	S	TOTAL
1	22.	16.	7.	107.	145.
2	22.	16.	7.	107.	145.
3	22.	16.	7.	107.	145.
4	22.	16.	7.	107.	145.
5	22.	16.	7.	107.	152.
6	22.	16.	7.	107.	152.
7	22.	16.	7.	107.	152.
8	21.	15.	7.	104.	147.
9	21.	15.	7.	104.	147.
10	21.	15.	7.	104.	147.
11	21.	15.	7.	104.	147.
12	21.	15.	7.	104.	147.
13	21.	15.	7.	101.	147.
14	21.	15.	7.	101.	147.
15	21.	15.	7.	101.	147.
16	20.	14.	7.	98.	139.
17	20.	16.	7.	102.	138.
18	20.	16.	7.	102.	138.
19	20.	16.	7.	102.	138.
20	20.	16.	7.	102.	138.

ANALYSIS OF PROJECTED PERSONNEL STRENGTHS,
LABORATORY A, OPTION 4

PD	S/T	S/C	P(UP)	P	P(LOW)	S/P	TC/P
1	4.76	6.32	21.03	19.33	17.78	23.96	29.14
2	4.72	6.49	20.91	19.23	17.67	24.39	29.68
3	4.86	6.68	20.14	18.51	17.01	25.70	31.27
4	4.86	6.68	20.14	18.51	17.01	26.94	32.60
5	4.86	6.79	19.87	18.25	16.77	28.58	34.37
6	4.86	6.90	19.60	18.00	16.54	30.26	36.20
7	4.88	6.96	19.30	17.73	16.29	31.80	37.85
8	4.90	7.03	19.01	17.46	16.03	32.54	38.72
9	4.92	6.98	18.98	17.44	16.02	32.83	39.07
10	4.95	6.93	18.95	17.41	16.00	33.12	39.42
11	4.95	6.93	18.95	17.41	16.00	33.60	39.99
12	4.91	6.88	19.14	17.58	16.15	33.77	40.20
13	4.88	6.94	19.05	17.50	16.07	34.44	40.96
14	4.84	6.78	19.51	17.93	16.47	34.10	40.52
15	4.83	6.57	19.96	18.35	16.87	33.31	39.61
16	4.90	6.48	19.96	18.35	16.86	33.31	39.63
17	4.97	6.29	20.22	18.59	17.09	32.86	39.16

DESIRED S/T RATIO IS 6.63
DESIRED S/C RATIO IS 6.69

COMPARISON OF REQUIRED AND PROJECTED
LABOR BUDGETS FOR OPTION 1,
LABORATORY B

FISCAL YEAR	REQUIRED BUDGET (\$X1000)	PROJECTED BUDGET (\$X1000)	PER CENT CHANGE
1	5056.	5563.	10.
2	5857.	6444.	10.
3	6815.	7498.	10.
4	7914.	8723.	10.
5	9205.	10127.	10.

PROJECTED PERSONNEL STRENGTHS,
LABORATORY B, OPTION 1

QTR	T	C	P	S	TOTAL
1	40.	34.	8.	240.	322.
2	40.	34.	8.	240.	322.
3	40.	34.	8.	240.	322.
4	40.	34.	8.	240.	322.
5	44.	37.	8.	264.	353.
6	44.	37.	8.	264.	353.
7	44.	37.	8.	264.	353.
8	44.	37.	8.	264.	353.
9	48.	40.	8.	290.	386.
10	48.	40.	8.	290.	386.
11	48.	40.	8.	290.	386.
12	48.	40.	8.	290.	386.
13	52.	44.	8.	319.	423.
14	52.	44.	8.	319.	423.
15	52.	44.	8.	319.	423.
16	52.	44.	8.	319.	423.
17	57.	48.	8.	350.	463.
18	57.	48.	8.	350.	463.
19	57.	48.	8.	350.	463.
20	57.	48.	8.	350.	463.

ANALYSIS OF PROJECTED PERSONNEL STRENGTHS,
LABORATORY B, OPTION 1

PD	S/T	S/C	P(UP)	P	P(LOW)	S/P	TC/P
1	5.94	6.77	23.04	21.18	19.47	53.02	61.21
2	5.98	6.75	23.17	21.30	19.58	54.46	62.85
3	5.99	6.76	23.29	21.41	19.68	55.13	64.73
4	5.99	6.78	23.45	21.55	19.81	58.07	66.92
5	5.99	6.81	23.60	21.69	19.94	59.99	69.09
6	5.99	6.83	23.75	21.83	20.07	61.90	71.25
7	5.99	6.85	23.90	21.97	20.19	63.78	73.38
8	6.01	6.89	23.99	22.05	20.26	66.16	76.06
9	6.02	6.92	24.08	22.13	20.33	68.53	78.71
10	6.03	6.91	24.29	22.32	20.52	70.50	80.95
11	6.04	6.90	24.50	22.52	20.69	72.45	83.17
12	6.06	6.91	24.63	22.63	20.80	75.09	86.12
13	6.08	6.92	24.75	22.74	20.90	77.70	89.05
14	6.11	6.92	24.87	22.85	21.00	80.28	91.96
15	6.13	6.93	24.99	22.96	21.10	82.85	94.85
16	6.13	6.95	25.16	23.12	21.25	85.63	97.98
17	6.13	6.96	25.33	23.28	21.39	88.39	101.08

ANALYSIS OF PROJECTED PERSONNEL STRENGTHS,
LABORATORY B, OPTION 2

PD	S/T	S/C	P(UP)	P	P(LOW)	S/P	TC/P
1	6.22	6.62	22.59	20.77	19.10	51.52	59.44
2	6.40	6.62	22.22	20.43	18.78	52.92	61.16
3	6.56	6.65	21.87	20.10	18.48	54.55	63.14
4	6.63	6.68	21.79	20.03	18.41	57.15	65.99
5	6.71	6.71	21.72	19.96	18.35	59.76	68.86
6	6.77	6.69	21.77	20.01	18.40	62.03	71.31
7	6.84	6.67	21.82	20.06	18.44	64.28	73.75
8	6.84	6.67	22.04	20.26	18.63	66.27	75.91
9	6.84	6.67	22.26	20.46	18.81	68.22	78.05
10	6.83	6.64	22.58	20.76	19.08	69.80	79.80
11	6.83	6.60	22.90	21.05	19.35	71.36	81.52
12	6.85	6.59	23.13	21.26	19.55	73.60	84.04
13	6.86	6.57	23.35	21.47	19.74	75.81	86.52
14	6.88	6.59	23.47	21.58	19.84	78.35	89.41
15	6.89	6.61	23.58	21.68	19.93	80.86	92.28
16	6.90	6.62	23.70	21.79	20.03	83.85	95.65
17	6.91	6.64	23.81	21.89	20.13	86.82	98.98

DESIRED S/T RATIO IS 6.94
DESIRED S/C RATIO IS 7.00

PROJECTED PERSONNEL STRENGTHS,
LABORATORY B, OPTION 2

QTR	T	C	P	S	TOTAL
1	37.	35.	8.	243.	315.
2	37.	35.	8.	243.	315.
3	37.	35.	8.	243.	315.
4	37.	35.	8.	243.	315.
5	39.	38.	8.	267.	344.
6	39.	38.	8.	267.	344.
7	39.	38.	8.	267.	344.
8	39.	38.	8.	267.	344.
9	43.	42.	8.	294.	379.
10	43.	42.	8.	294.	379.
11	43.	42.	8.	294.	379.
12	43.	42.	8.	294.	379.
13	47.	47.	8.	324.	418.
14	47.	47.	8.	324.	418.
15	47.	47.	8.	324.	418.
16	47.	47.	8.	324.	418.
17	51.	51.	8.	354.	456.
18	51.	51.	8.	354.	456.
19	51.	51.	8.	354.	456.
20	51.	51.	8.	354.	456.

PROJECTED PERSONNEL STRENGTHS,
LABORATORY B, OPTION 3

QTR	T	C	P	S	TOTAL
1	40.	34.	8.	240.	322.
2	40.	34.	8.	240.	322.
3	40.	34.	8.	240.	322.
4	40.	34.	8.	240.	322.
5	44.	37.	8.	264.	353.
6	44.	37.	8.	264.	353.
7	44.	37.	8.	264.	353.
8	44.	37.	8.	264.	353.
9	48.	40.	8.	290.	386.
10	48.	40.	8.	290.	386.
11	48.	40.	8.	290.	386.
12	48.	40.	8.	290.	386.
13	52.	44.	8.	319.	423.
14	52.	44.	8.	319.	423.
15	52.	44.	8.	319.	423.
16	52.	44.	8.	319.	423.
17	57.	48.	8.	350.	463.
18	57.	48.	8.	350.	463.
19	57.	48.	8.	350.	463.
20	57.	48.	8.	350.	463.

ANALYSIS OF PROJECTED PERSONNEL STRENGTHS,
LABORATORY B, OPTION 3

PD	S/T	S/C	P(UP)	P	P.(LOW)	S/P	TC/P
1	5.94	6.77	23.04	21.18	19.47	53.02	61.21
2	5.98	6.75	23.17	21.30	19.58	54.46	62.85
3	5.99	6.76	23.29	21.41	19.68	56.13	64.73
4	5.99	6.78	23.45	21.55	19.81	58.07	66.92
5	5.99	6.81	23.60	21.69	19.94	59.99	69.09
6	5.99	6.83	23.75	21.83	20.07	61.90	71.25
7	5.99	6.85	23.90	21.97	20.19	63.78	73.38
8	6.01	6.89	23.99	22.05	20.26	66.16	76.06
9	6.02	6.92	24.08	22.13	20.33	68.53	78.71
10	6.03	6.91	24.29	22.32	20.52	70.50	80.95
11	6.04	6.90	24.50	22.52	20.69	72.45	83.17
12	6.06	6.91	24.63	22.63	20.80	75.09	86.12
13	6.08	6.92	24.75	22.74	20.90	77.70	89.05
14	6.11	6.92	24.87	22.85	21.00	80.28	91.96
15	6.13	6.93	24.99	22.96	21.10	82.85	94.85
16	6.13	6.95	25.16	23.12	21.25	85.63	97.98
17	6.13	6.96	25.33	23.28	21.39	88.39	101.08

PROJECTED PERSONNEL STRENGTHS,
LABORATORY B, OPTION 4

QTR	T	C	P	S.	TOTAL
1	37.	35.	8.	243.	315.
2	37.	35.	8.	243.	315.
3	37.	35.	8.	243.	315.
4	37.	35.	8.	243.	315.
5	39.	38.	8.	267.	344.
6	39.	38.	8.	267.	344.
7	39.	38.	8.	267.	344.
8	39.	38.	8.	267.	344.
9	43.	42.	8.	294.	379.
10	43.	42.	8.	294.	379.
11	43.	42.	8.	294.	379.
12	43.	42.	8.	294.	379.
13	47.	47.	8.	324.	418.
14	47.	47.	8.	324.	418.
15	47.	47.	8.	324.	418.
16	47.	47.	8.	324.	418.
17	51.	51.	8.	354.	456.
18	51.	51.	8.	354.	456.
19	51.	51.	8.	354.	456.
20	51.	51.	8.	354.	456.

ANALYSIS OF PROJECTED PERSONNEL STRENGTHS,
LABORATORY B, OPTION 4

PD	S/T	S/C	P(UP)	P	P(LOW)	S/P	TC/P
1	6.22	6.62	22.59	20.77	19.10	51.52	59.44
2	6.40	6.62	22.22	20.43	18.78	52.92	61.16
3	6.56	6.65	21.87	20.10	18.48	54.55	63.14
4	6.63	6.68	21.79	20.03	18.41	57.15	65.99
5	6.71	6.71	21.72	19.96	18.35	59.76	68.86
6	6.77	6.69	21.77	20.01	18.40	62.03	71.31
7	6.84	6.67	21.82	20.06	18.44	64.28	73.75
8	6.84	6.67	22.04	20.26	18.63	66.27	75.91
9	6.84	6.67	22.26	20.46	18.81	68.22	78.05
10	6.83	6.64	22.58	20.76	19.08	69.80	79.80
11	6.83	6.60	22.90	21.05	19.35	71.36	81.52
12	6.85	6.59	23.13	21.26	19.55	73.60	84.04
13	6.86	6.57	23.35	21.47	19.74	75.81	86.52
14	6.88	6.59	23.47	21.58	19.84	78.35	89.41
15	6.89	6.61	23.58	21.68	19.93	80.86	92.28
16	6.90	6.62	23.70	21.79	20.03	83.85	95.65
17	6.91	6.64	23.81	21.89	20.13	86.82	98.98

DESIRED S/T RATIO IS 6.94
DESIRED S/C RATIO IS 7.00

APPENDIX F

OTHER PROGRAMS USED IN ANALYSIS

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*NAME. RATIO
*IOCS(CARD,1132PRINTER)
*ONE WORD INTEGERS
  DIMENSION TA(50),CA(50),BA(50),SA(50)
  DIMENSION TECHA(50),TECHB(50),CLERA(50),CLERB(50)
  DIMENSION BUSPA(50),BUSPB(50),SCIEA(50),SCIEB(50)
  DIMENSION TITLE(60)
  READ(2,1)N,TITLE
  DO 4 I=1,N
4  READ(2,3)TECHA(I),CLERA(I),BUSPA(I),SCIEA(I)
  READ(2,1)N,TITLE
  DO 5 I=1,N
5  READ(2,3)TECHB(I),CLERB(I),BUSPB(I),SCIEB(I)
  DO 25 J=1,6
  M=J
  DO 19 I=1,N
  TA(I)=SCIEA(I)/TECHA(I)
  CA(I)=SCIEA(I)/CLERA(I)
  BA(I)=SCIEB(I)/TECHB(I)
19 SA(I)=SCIEB(I)/CLERB(I)
  CALL MVAVG(TA,N,M)
  CALL MVAVG(CA,N,M)
  K=J+2
  CALL MVAVG(BA,N,M)
  CALL MVAVG(SA,N,M)
  WRITE(3,6)
  WRITE(3,17)
  NR=N-M+1
  DO 20 I=1,NR
20 WRITE(3,10)I,TA(I),BA(I),CA(I),SA(I)
  CALL TTSTT(TA,NR,BA,NR,4,NDF,ANS1)
  CALL TTSTT(CA,NR,SA,NR,4,NDF,ANS2)
  WRITE(3,7)ANS1,ANS2,NDF
25 CONTINUE
  1 FORMAT(I2,60A1)
  3 FORMAT(12F6.0)
  6 FORMAT(//////////,1H1)
  7 FORMAT(//,25X,'COMPUTED T = ',F8.5,11X,'COMPUTED T = '
  1,F8.5,/,34X,'NUMBER OF DEGREES OF FREEDOM = ',I2,/)
  10 FORMAT(20X,I5,4F14.5)
  17 FORMAT(22X,'QTR',8X,'S/T-A',9X,'S/T-B',9X,'S/C-A',9X,
  1'S/C-B',/)
  STOP
  END

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```

*NAME RESID
*ONE WORD INTEGERS
*IOCS(CARD,1132PRINTER)
  DIMENSION T(40),C(40),B(40),S(40),TT(40),P(40)
  DIMENSION TITLE(70),Q(40),Z(40)
  READ(2,2)A,D,X,Y
  WRITE(3,6)
  100 READ(2,1)N,TITLE

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```

WRITE(3,7)
R=1.0
V=1.0
DO 4 I=1,N
READ(2,3)T(I),C(I),B(I),S(I),P(I),Q(I)
TT(I)=T(I)+C(I)+B(I)+S(I)
ST=S(I)/T(I)
ST=ALOG(ST)
SC=S(I)/C(I)
SC=ALOG(SC)
TT(I)=ALOG(TT(I))
TT(I)=ALOG(TT(I))
P(I)=R*P(I)+V*Q(I)
P(I)=ALOG(P(I))
Q(I)=A+D*TT(I)+X*ST+Y*SC
Z(I)=P(I)-Q(I)
AA=EXP(P(I))
AB=EXP(Q(I))
AC=AA-AB
4 WRITE(3,8)I,P(I),AA,Q(I),AB,Z(I),AC
CALL TTSTT(P,N,Q,N,4,NDF,ANS)
WRITE(3,9)ANS,NDF
ZSQ=0.0
ZZ=0.0
FN=N
FM=N-1
DO 10 I=1,N
10 ZSQ=ZSQ+Z(I)**2
DO 11 I=2,N
J=I-1
11 ZZ=ZZ+(Z(J)-Z(I))**2
ZSQ=ZSQ/FN
ZZ=ZZ/FM
ZZ=ZZ/ZSQ
WRITE(3,12)ZZ
PAUSE
1 FORMAT(I5,70A1)
2 FORMAT(7F10.0)
6 FORMAT(1H1)
7 FORMAT(22X,'OBSERVED',9X,'ESTIMATED',/,12X,'NO.',8X,
1'OUTPUT',11X,'OUTPUT',13X,'RESIDUAL',/)
3 FORMAT(12F6.0)
8 FORMAT(9X,I5,F10.3,2X,1H(,F5.2,1H),F10.3,2X,1H(,
1F5.2,1H),F10.3,2X,1H(,F5.2,1H))
9 FORMAT(/,32X,'COMPUTED T = ',F8.5,/,30X,'DEGREES OF
1FREEDOM = ',I2)
12 FORMAT( /,27X,'VON NEUMANN'S RATIO = ',F8.5,/)
GO TO 100
200 CONTINUE
STOP
END

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SUBROUTINE TTSTT(A,NA,B,NB,NOP,NDF,ANS)
DIMENSION A(1),B(1)
NDF=0
ANS=0.0
ABAR=0.0
DO 110 I=1,NA
110 ABAR=ABAR+A(I)
FNA=NA
ABAR=ABAR/FNA
BBAR=0.0
DO 120 I=1,NB
120 BBAR=BBAR+B(I)
FNB=NB
BBAR=BBAR/FNB
IF(NOP-4)122,180,200
122 IF(NOP-1)200,135,125
125 SA2=0.0
DO 130 I=1,NA
130 SA2=SA2+(A(I)-ABAR)**2
SA2=SA2/(FNA-1.0)
135 SB2=0.0
DO 140 I=1,NB
140 SB2=SB2+(B(I)-BBAR)**2
SB2=SB2/(FNB-1.0)
GO TO (150,160,170),NOP
150 ANS=((BBAR-ABAR)/SQRT(SB2))*SQRT(FNB)
NDF=NB-1
GO TO 200
160 NDF=NA+NB-2
FNDF=NDF
S=SQRT(((FNA-1.0)*SA2+(FNB-1.0)*SB2)/FNDF)
ANS=((BBAR-ABAR)/S)*(1.0/SQRT(1.0/FNA+1.0/FNB))
GO TO 200
170 ANS=(BBAR-ABAR)/SQRT(SA2/FNA+SB2/FNB)
A1=(SA2/FNA+SB2/FNB)**2
A2=(SA2/FNA)**2/(FNA+1.0)+(SB2/FNB)**2/(FNB+1.0)
NDF=A1/A2-2.0+0.5
GO TO 200
180 SD=0.0
D=BBAR-ABAR
DO 190 I=1,NB
190 SD=SD+(B(I)-A(I)-D)**2
SD=SQRT(SD/(FNB-1.0))
ANS=(D/SD)*SQRT(FNB)
NDF=NB-1
200 RETURN
END

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VITA

Leonard Sherwood Yarbrough

Candidate for the Degree of

Doctor of Philosophy

Thesis: THE IMPACT OF FISCAL CHANGE UPON RESEARCH ORGANIZATION STAFFING STRATEGY

Major Field: Engineering

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